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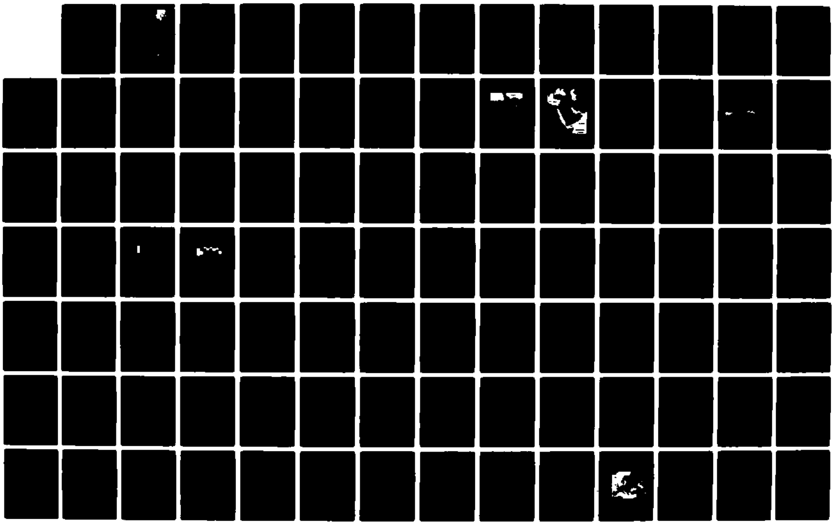

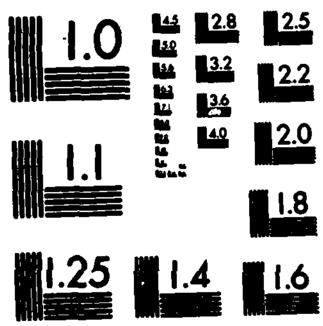

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CROSS CORRELATION ANALYSIS TO DETERMINE THE ENVIRONMENTAL PARAMETERS CORRELATED WITH ELECTRO-OPTICAL SYSTEM PERFORMANCE

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Sensor effectiveness in operational environments often depends on several environmental parameters, not only individually but, because they are often at least partly correlated, on the peculiar real world combinations in which they occur. While the statistical occurrence of various parameter combinations can be derived from weather observation records, correlated parameter statistics are not generally available, and, in any case, have limited utility because they do not directly transform to system performance characteristics. In this study,

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figures of merit associated with Electro-Optical (EO) sensor performance were calculated for individual synoptic conditions reported over a three year period of record for locations of interest. Using the resulting data base, which included the calculated figures of merit, as well as the weather parameters upon which they were based, performance statistics were developed and cross correlations performed; several potentially useful parameter correlations were found.

FOREWORD

The work was performed over the period July 1980 to December 1980 for the Avionics Laboratory (AAW), Air Force Wright Aeronautical Laboratories, under Contract Number F33615-78-C-1557. The Project Engineer was Mr. Michael K. Murray (AFWAL/AAWA-1).

Significant assistance in computer implementation was provided by Mr. William K. McQuay (AFWAL/AAWA-1), whose help is gratefully acknowledged.

This study was conducted by the Defense Science Division of Science Applications, Incorporated (SAI) and staff meteorologist at the Avionics Laboratory. The authors wish to acknowledge the contribution of Ron Nelson (SAI) for his contributions in the area of data quality assurance, and for numerous useful suggestions. The authors also wish to acknowledge the efforts of Major Michael R. Snapp (AFWAL/WEA), Mr. Frank W. Jenks, III (AFWAL/WEA), Mr. Rich F. Coleman (SAI) and Lt.Col. Ed Tomlinson (AFWAL/WE) for their assistance in final review of this report. The authors wish to thank Dr. E. Alan Phillips for his scientific review of the material presented herein, and numerous helpful suggestions. Finally, the authors are especially grateful for the numerous contributions and considerable effort of Mrs. Melody S. Stout (SAI) in review and preparation of the final manuscript.

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ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
AAA	Anti-Aircraft Artillery
AFATL	Air Force Armament Test Laboratory
AFWAL	Air Force Wright Aeronautical Laboratories
CFLOS	Cloud-Free-Line-Of-Sight
CNA	Center for Naval Analysis
DoD	Department of Defense
EO	Electro-Optical
USAFETAC	United States Air Force Environmental Technical Applications Center
^{o}F	Degrees Fahrenheit
FLIR	Forward Looking Infrared (sensor)
ft	Foot
G[illegible]	Greenwich Mean Time
HEL	High Energy Laser
IR	Infrared
km	kilometer
LOS	Line-of-Sight
MTF	Modulation Transfer Function
mm	Millimeter
OASMA	Offensive Air Support Mission Analysis
OUSDR&E	Office of the Under Secretary of Defense for Research and Engineering
RF	Radio Frequency

ACRONYMS AND ABBREVIATIONS (Continued)

Abbreviation	Definition
SAI	Science Applications, Incorporated
SAM	Surface-to-Air Missile
um	Micrometer

SECTION 1

INTRODUCTION

1.1 THE ELECTRONIC WARFARE BATTLEFIELD

Electronic Warfare is a major element of modern military operations that increases in importance with each passing year. This emphasis is a result of the increased force effectiveness associated with electronic, optical and Electro-Optical (EO) sensors. For example, directing Anti-Aircraft Artillery (AAA) or Surface-to-Air Missiles (SAMs) by radar and/or EO sensors makes these weapons vastly more effective than their World War II counterparts. However, great reductions in the effectiveness of these sensors are possible when countermeasures are effectively employed. When successful countermeasures are applied (e.g., Flares, which defeat the seeker on a heat-seeking missile), the expensive "smart" weapon becomes an expensive "dumb" weapon, without even the minimal effectiveness associated with conventional "saturation fire". Of course, to every countermeasure there can be a counter-countermeasure, and so on.

An example of the effectiveness of countermeasures was provided in the Arab-Israeli War of 1973. In the first week of the conflict, Israeli aircraft took severe losses from radar-directed SA-6 missiles and ZSU-23-4 AAA. Aircraft losses dropped dramatically when newer F-4's, with new chaff, decoy flares, and warning receivers were deployed.

Of particular relevance to this study is the increasing use of optical, Infrared (IR), and other EO systems, either alone or in conjunction with Radio Frequency (RF) systems. Because of the wavelengths involved (roughly 0.1-14.0 micrometers (um)), these systems can achieve far better resolution and accuracy than is possible with RF systems. Furthermore, these systems, particularly imaging systems, are very difficult to defeat using conventional countermeasures. On the other hand, due to the wavelengths used, these systems are often greatly affected by the prevailing weather. The same weather conditions may also affect different systems (e.g., a sensor and a countermeasure) in different ways, depending on the respective wavelengths, sensitivities, and modes of operation. Characterization of these effects is very difficult. One reason is the great magnitude of weather parameter variations, typically over several orders of magnitude (e.g., visibility variations from a few tens of meters to tens of kilometers). Another reason is the rapidity of change, with dramatic weather changes possible in a matter of hours or less, and over distances as small as hundreds of meters and typically in tens of miles. Finally, the different factors which make up "gross weather" vary in ways which are neither completely independent nor fully correlated. First principles, theoretical treatments which attempt to assess the effects of gross weather on sensors are very difficult.

The main thrust of this report is to document a methodology for addressing the relationship between weather and factors related to the performance of optical, IR and EO systems. The report presents some results applicable to the European environment and other parts of the world. These results document the effect of weather on a variety of parameters and figures of merit relevant to optical, IR and EO systems.

1.2 WEATHER ON THE ELECTRONIC WARFARE BATTLEFIELD

It is an established fact that the condition of the atmosphere plays an important role in determining the effectiveness of EO systems. The weather frequently not only affects, but can drive the performance of these systems. As a result, Air Force interest in the performance of such systems in operational theaters is growing. Strong interest has also been voiced at the Department of Defense (DoD) level:

> The high technology weapons currently being developed or deployed within the DoD are bringing with them a new concern for the adverse effects of weather.... The subject of "all weather" capability has become increasingly prominent in reviews and decisions made at senior levels within the DoD. Weapon systems are often compared on the basis of their weather sensitivities, but it is not at all clear exactly how these sensitivities or "all weather" capabilities are evaluated.
>
> -- Ruth Davis (1)
> Deputy Under Secretary
> OUSDR&E, 1979

This report will use the term "climatology" in a broad, somewhat untraditional sense. Specifically, as used here, "climatology" refers to statistics describing the variations of some parameter(s), related to environmental variations, based on a sample including a large number of individual realizations (i.e., actual values "drawn" from the range of possibilities) of the parameter(s) over a multi-year period. This fits quite well with "climatology" used in the traditional sense. For example, to get a temperature climatology, one would begin with thousands of temperature measurements taken over a period of many years. From such a sample, means, medians, occurrence statistics, etc., broken out for the entire sample, or by season, time of day, etc., could be calculated. A relative humidity climatology would be derived similarly, except that this parameter is generally calculated, on an observation-by-observation basis, from other parameters (temperature, dew point temperature, pressure) to obtain the individual realizations.

Relating the performance of EO systems, such as imaging IR sensors, to standard weather climatologies has been the subject of a number of recently published reports (e.g., (2,3,4)). A key to achieving this objective is through understanding the effects of the atmosphere and the geophysical environment on phenomena such as atmospheric transmission, path radiance, natural emissions or reflections of a target or background, etc.

Because parameters which directly affect the performance of most EO systems (e.g., the transmission in a particular IR band) are not routinely measured, climatologies based on direct observations are not available for such parameters. Often, however, physical or empirical relationships do exist which enable the analyst to infer the values of these "EO parameters" based upon the behavior of routinely measured weather variables. Once the necessary EO parameters are inferred, system performance models can be used to calculate the performance of an EO system (e.g., an IR Warning Receiver, Laser Countermeasure, Forward Looking IR (FLIR), etc.) for the conditions observed. Thus, one should be able to go back through weather records and compute "EO climatologies": i.e.. climatologies which include modeled EO parameters as well as standard weather parameters.

To date, only a few published studies (e.g., (2,3)) have included any derived EO paramters. Hence, EO climatologies are not available for most systems. As a result, system effectiveness studies have adopted assumptions and approximations which are generally unsatisfactory. Typically, the standard frequency climatologies are used, or some qualitative index is adopted which incorporates intuitive correlations. Use of standard, single variable frequencies can lead to erroneous conclusions. The numerous factors affecting system performance are generally at least partly correlated in the real world, and these correlations are lost when single variable frequencies are employed.

For example, a recent study (3) demonstrated that increased wind speed was correlated with poorer performance of a High Energy Laser (HEL) weapon system, even though the only direct effect of high wind speed is to minimize the thermal blooming parameter, thus improving laser performance. However, in the real world, high wind speeds are correlated with a variety of bad weather types (e.g., storms, rain squalls, etc.), which degrade atmospheric transmission more than enough to compensate for the benefits conveyed by the reduction in thermal blooming.

Even, however, if the parameter correlations are known, their relative weight in determining system performance will typically vary depending on the use of the system of interest and the values of the parameters themselves. Simple performance indices generally cannot allow for the fact that one factor may influence the performance of a system by being very bad (or very good) when, for example, any of several other correlated parameters may have an opposite effect. The permutations of the real world are simply too complicated for easy assessments.

An existing study which associates IR sensor performance with weather conditions is the Offensive Air Support Mission Analysis (OASMA) Study (4). This study assigned aviation weather thresholds for visual and IR sensor operations (e.g., visual: Daylight hours, 3,000 foot (ft) ceiling, 3 mile visibility; IR: All hours, 300 ft ceiling, 1 mile visibility). Based upon these assessments, sensor comparisons were made, comparing how often visual versus IR sensors could be used for various Seasons and locations.

A weakness of the OASMA assessments was that its estimates of the variation of sensor performance with real world weather variations were based upon single-parameter statistics. That is, visibility, for example, was varied independently of changes in other weather parameters (e.g., humidity) to estimate associated sensor performance variations. In operational environments, however, combinations of weather tend to occur together. For example, high extinction conditions (e.g., rain) tend to occur in combination with heavy cloud cover.

Furthermore, several phenomena affect the performance of a sensor. Weather affects inherent scene signatures and inherent target signatures (for passively heated targets), as well as transmission of these signatures to the sensor. Unless the correlated effect of all weather parameters on these factors (i.e., inherent signatures and atmospheric transmission) taken together, is assessed, the validity of simple, single-parameter weather thresholds is subject to significant doubt.

This study replaces the intuition employed in other studies with a quantitative approach to the parameter correlations problem, but still relies upon relations which infer EO parameters from standard meteorological quantities. These relationships range from partly physical/partly empirical to totally empirical. The absolute performance values derived are only as good as the relationships used to establish the performance for each observation taken.

The results presented in this report will be useful primarily as a means for comparing non-standard (i.e., EO) climatologies for a few sites in Europe and the Near East, chosen because they are representative of a variety of climatological conditions, and because they are in parts of the world often chosen for tactical or strategic studies.

In addition, this methodology can be used to support EO system concept definition studies and in developing system deployment strategies, by developing modeled climatologies of parameters directly relevant to the systems of interest. While an inferred climatology is no substitute for a long-term measurements program, it can be a significant improvement over "seat of the pants" estimates, and over estimates based on inferences from statistics of a single parameter (e.g., visibility).

SECTION 2

APPROACH

2.1 SOURCE OF THE DATA

The United States Air Force Environmental Technical Applications Center (USAFETAC) supplied three years of synoptic observation data from about six hundred stations in Europe, the Near East, the Soviet Union, and the United States. The data for each station includes standard surface weather observations at three hour intervals. The years supplied were 1977, 1978, and 1979.

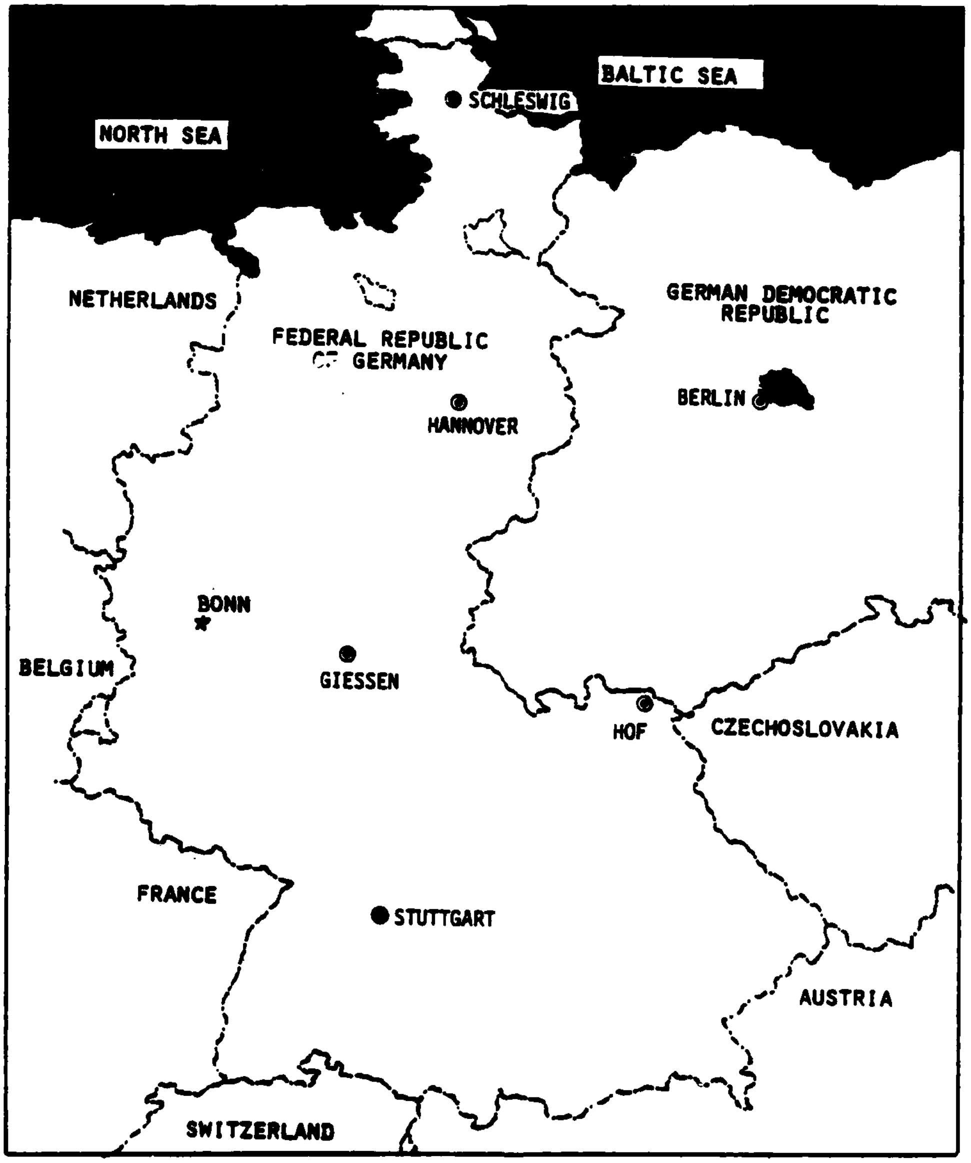
The twelve stations selected for analysis in this report are listed in Table 1. Their geographical locations are depicted in Figure 1. These stations were selected to represent geographical areas of interest to military analysts.

2.2 QUALITY CONTROL

This particular period of record was selected partly on the basis of the quality control which had been applied to the data by USAFETAC. As part of the normal process of generating synoptic data archives (5), checks are made for gross errors (e.g., dew point greater than temperature). In addition, a variety of tests were implemented after delivery of the data to the Air Force Wright Aeronautical Laboratories (AFWAL). These included manual inspection of the data, which revealed no serious difficulties (6); observation density tests, which showed most months and times to be uniformly covered by observations in Europe (except for 2100, 0000, and 0300 in Giessen during October, November, and December in 1978); and limited use

Table 1. Selected Weather Station Locations

STATION NUMBER	LOCATION NAME	LATITUDE (Deg, Min)	LONGITIDE (Deg, Min)	ELEVATION (Meters)
100350	Schleswig	54° 32' North	9° 33' East	43
103380	Hannover	52° 28' North	9° 42' East	55
093850	Berlin	52° 23' North	13° 31' East	47
105320	Giessen	50° 34' North	8° 42' East	186
106850	Hof	50° 19' North	11° 53' East	567
107380	Stuttgart	49° 01' North	12° 04' East	376
402700	Amman	31° 39' North	35° 59' East	767
407540	Tehran	35° 41' North	51° 19' East	1204
403720	Kuwait	29° 13' North	47° 59' East	55
408750	Bandar-Abbas	27° 11' North	56° 17' East	9
404380	Riyadh	24° 42' North	46° 44' East	624
405760	Sana	15° 31' North	44° 11' East	2206



⊙ Weather Station

Figure 1a. Map of Selected European Weather Station Locations.

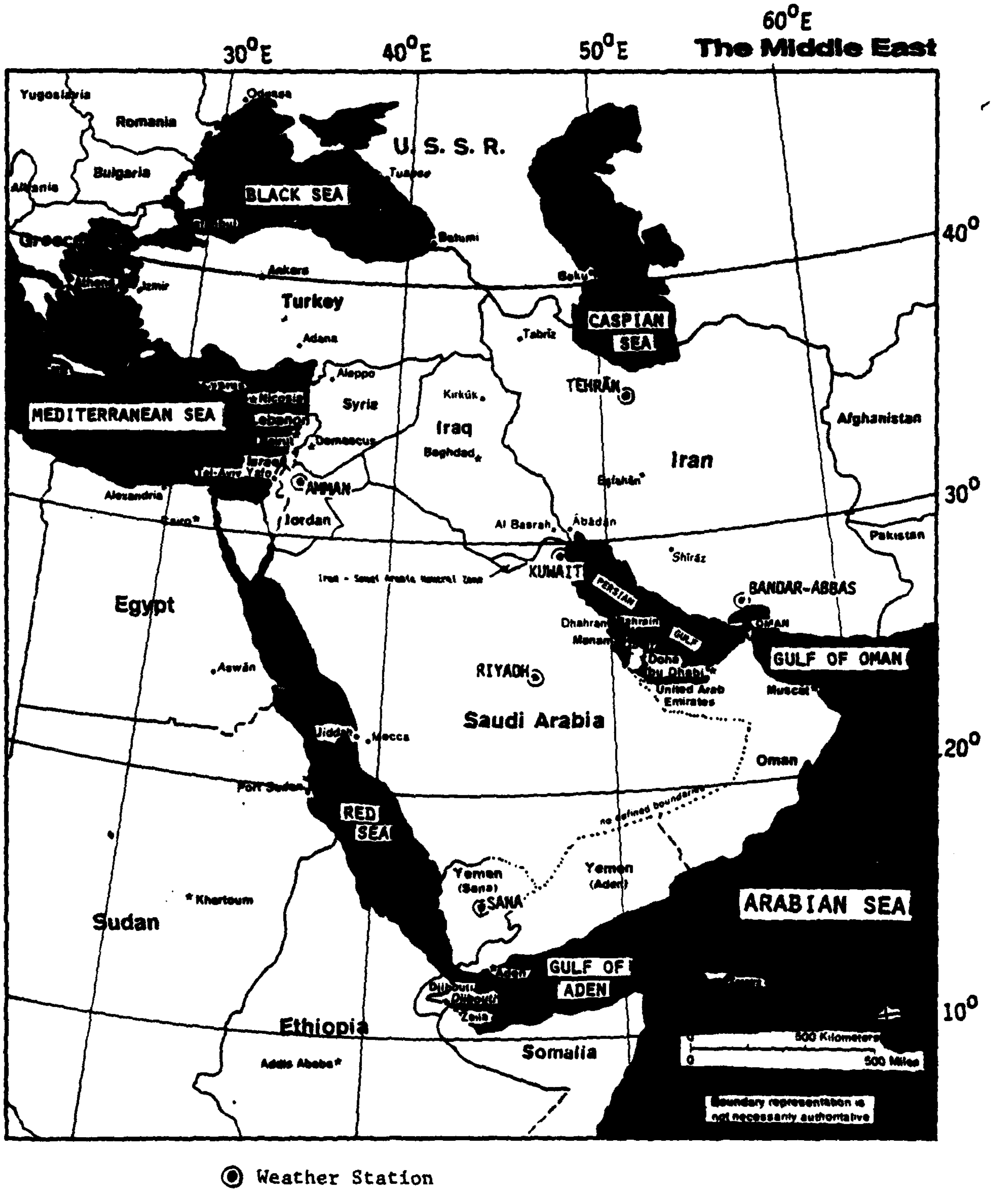


Figure 1b. Map of Selected Middle East Weather Station Locations.

of automated error checking techniques. These checked for non-existent cloud height codes (occurrence less than 0.03 percent), wind speed greater than wind gust speed (virtually no occurrences), and other inconsistencies which proved not to be a problem. Overall, the European stations constituted a very "clean" data set. The Near Eastern stations also demonstrated very few errors, but coverage was often very sporadic.

2.3 EO SYSTEM PARAMETERS

After ensuring a "clean" data base of meteorological observations, the associated EO parameters had to be calculated for each observation. This, in turn, required selecting a scenario, because the effect of the weather upon a system depends upon the scenario itself. As a simple example, clouds do not obstruct Line-of-Sight (LOS) in engagements which occur entirely beneath them.

2.3.1 The Scenario

A typical tactical scenario involving aircraft and EO systems involves the aircraft flying in at "tree top" level in order to avoid exposure to enemy defenses. For these tactics, operating within a few hundred meters of the surface, the climatologies based solely on surface weather observations can be considered to be representative of the "tree top" weather.

Since only surface data were made available, we have restricted our study to performance of systems in scenarios where surface data is representative. The lowest layer of the atmosphere can be adequately characterized by the surface observations available in the data base, combined with simple models of the earth's boundary layer, which provide vertical profiles scaled to the surface values.

Similarly, clouds are only important to such an analysis in determining the upper boundary of the engagement volume and insofar as they affect surface parameter values (e.g., insolation). Except when sky obscurations are caused by low surface visibilities due to fog, falling precipitation, or other restrictions, the cloud base coverage, type, and height are reported in surface observations to an accuracy sufficient for this analysis.

The basic scenario geometry is shown in Figure 2. The authors selected a low altitude scenario because all elements were as close to the ground as possible. This minimizes the potential errors involved in extrapolating surface conditions to normal flight altitudes. Four kilometers (km) was selected as a typical path distance, based upon an estimate of the range at which a low aircraft might attempt to engage a surface target. The wavelengths chosen for analysis were the visible, 3-5 um, and the 8-12 um spectral bands.

2.3.2 The Key Parameters

Full performance prediction models are not available to determine the performance of optical, IR, and EO systems in the field. Instead, key EO parameters can be calculated which are closely associated with the performance of such a system and can be used to give an estimate of system performance in the field. Two parameters were chosen for this role: Transmission over a 4 km horizontal path and a figure of merit based in part on solar flux. The basic models used to calculate these parameters and the meteorological observables used as inputs are shown in Table 2. A description follows.

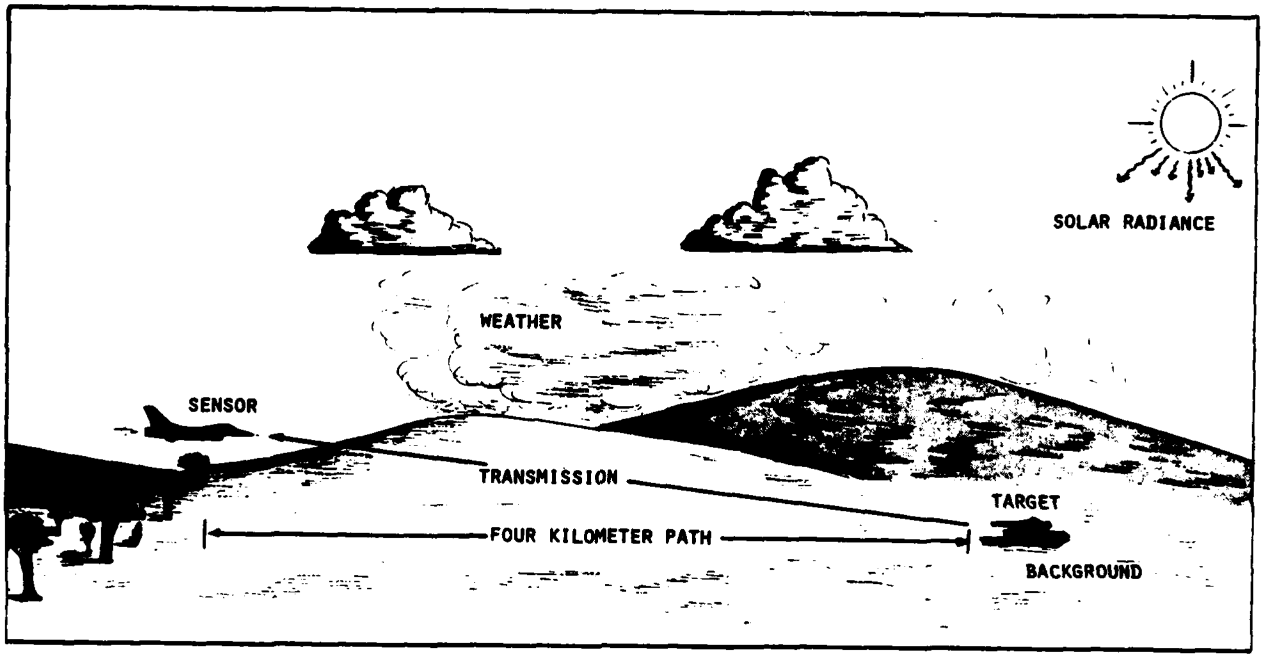


Figure 2. Basic Engagement Scenario Geometry.

Table 2. Summary of Important Surface Meteorological and Micro-Meteorological Parameters for EO Systems.

MICRO-MET PARAMETER	CORRELATION MODEL USED TO CALCULATE	INPUT/VARIABLES/ OBSERVABLES
SPECTRAL EXTINCTION		
Gaseous Extinction	LOWTRAN 5	Pressure
		Temperature
		Absolute Humidity
Aerosol Extinction	LOWTRAN 5	Visibility
		Relative Humidity
		Aerosol Type
		Fog Type
Fog Type Model	Stewart & Essenwanger	6-hour Temperature Change
		Wind Speed
		Cloud Cover
		Precipitation
Precipitation Extinction	CNA Rain Rate Model;	Present Weather
	Rensch & Long	Rain Rate
SOLAR FLUX	Atwater & Ball	Layered Cloud Cover
		Cloud Type
		Visibility
		Absolute Humidity
		Latitude
		Longitude
		Time of Day
		Day of Year

2.3.2.1 Transmission

The 4 km transmission was actually calculated for three possible bands: The visible band, 3-5 um, and 8-12 um. For non-precipitation cases, LOWTRAN 5 (7) was used. For visible band 4 km transmission, the value was taken directly from the visibility, assuming the .02 contrast threshold associated with traditional definitions of visual range. That is, $T_{vis} = e^{-4a}$, where a is the visible extinction coefficient = 3.91/visibility (Koschmieder formula). To calculate 3-5 um and 8-12 um 4 km transmission, LOWTRAN uses the "meteorological range," taken to be 1.3 times the visibility (7). When fog was reported, a model by Stewart and Essenwanger (8) was used to select between the FOG1 model (Radiation Fog) and the FOG2 model (Advection Fog), with advection fog assumed in ambiguous cases. Based on suggestions by Biberman (2), the maritime aerosol distribution was assumed for all European Stations. A rural aerosol distribution was assumed for Near East Stations.

Where precipitation was reported, a special procedure was applied. Values taken from a Center for Naval Analysis (CNA) report (9) were used to determine rain rate from the present weather code. Then, a model by Rensch & Long (10) was used to calculate visible extinction based upon the rain rate. This value was subtracted from the overall visible extinction based on visibility (11), and a "rainless visibility" estimated. The rainless visibility was used in LOWTRAN 5 to obtain 3-5 and 8-12 um extinction in 100 percent humidity non-precipitation conditions. Finally, the rain-rate-based extinction (assumed to be the same at visible and IR wavelengths) was added to the rainless extinction at each wavelength to yield a rain-modified extinction value.

Where the precipitation form was snow, a "bogus" precipitation value of rain rate = 25 millimeters per hour (mm/hr) was applied. Since no real snow-induced extinction model was available at the time of this analysis, this represents a very crude assumption: That snow, when it occurs at all, induces a relatively high extinction (about 1.9/km in both IR bands, and about 2.6/km in the visible; somewhere between "heavy" and "excessive" rain). We note that this "bogus" value corresponds to a visibility of about 1.5 km. Where reported visibility was higher (hence, visible extinction less than 2.6/km), the overall extinction was lowered proportionately.

2.3.2.2 Solar Flux

The performance of an imaging IR system is only partially determined by the atmospheric attenuation of an inherent signal emanating from a source (target) and its immediate background. Another major factor is the inherent target or background signal itself. For this reason, a climatological or statistical study which tries to infer the performance of any imaging IR system without including the effects of weather on the inherent target and background radiance level may be seriously deficient.

In this study an attempt is made to include solar loading in order to estimate the inherent target and background signatures. Solar loading is expected to have a significant effect on imaging IR systems performance (12). Solar flux is computed using a model (13) which uses only surface weather observations, including cloud types and coverage. When combined with atmospheric transmission statistics, solar flux levels allow calculation of "figures of merit" (see Section 2.4) which estimate the overall performance of IR systems.

2.4 EO SYSTEM PERFORMANCE

Ultimately, to produce EO system performance statistics, one would like a comprehensive performance model which would include all the geophysical and atmospheric factors affecting inherent target and background radiance, contrast transmission, and the specific system characteristics, e.g., Modulation Transfer Functions (MTF), resolution, sensitivity, and others. Unfortunately, such models are not currently available. Thus, the final goal of this study effort will only be achieved after considerably more analysis of target/background data is accomplished, and only after a better understanding of some important physical processes is attained.

For the moment, one is justified in more simple comparisons; looking at segments of weather data organized by Season, time of day, and geographic regions. Relative EO system performance is inferred from functional relationships describing the correlation with other geophysical and atmospheric parameters.

The two significant factors in determining climatologies of EO system performance (themselves complicated functions of many atmospheric and geophysical parameters) are atmospheric transmission and the target/background inherent radiance contrast. Based on a methodology described by Friedman (12), a "figure of merit" was devised to account for these two factors. Sensor performance will depende on the apparent (i.e., at the sensor) target/background contrast, a product of the inherent scene contrast, multiplied by the contrast transmission of the atmosphere. Where path radiance and multiple scattering are small, this can be estimated from the inherent target and background radiance, each multiplied by the direct atmospheric transmission. Since the target and background radiances may both be strongly affected by insolation, a figure of merit may take the form:

$$M = T^n * F^m$$

where T is the atmospheric transmission (dimensionless); F is the solar flux at the target (typically in W/m^2 units), and n and m are empirically determined constants. Suggested forms for figures of merit are given in Table 3. Values of m were chosen from 0 to 2 to bracket a significant range of possible relationships.

Table 3. Possible Figures of Merit for Imaging IR Sensor Using Transmission and Solar Flux.

$$M = T$$

$$M = T \times F^{1/2}$$

$$M = T \times F$$

$$M = T \times F^{3/2}$$

$$M = T \times F^{2}$$

$$M = T \times F \times e^{-V_w/K}$$

M	=	Figure of Merit
T	=	Transmission in wave band of interest
F	=	Solar Flux
V_w	=	Wind Velocity
K	=	Empirical Constant

Note: Because M is a relative figure of merit, any units may be used, provided they are consistently applied.

This formulation implies that target/background contrast is a function only of isolation, except for the m=0 case, where contrast is constant. For those targets for which heating is almost entirely external (i.e., no major internal heat sources such as running engines), a preliminary analysis of target/background radiance data collected by the Air Force Armament Test Laboratory (AFATL), Eglin AFB, (14) supports this approximation. Significant parameters, as determined by means of a regression analysis of AFATL's measured target/background radiance data and the accompanying meteorological data, appear to be cloud coverage and wind speed in that order. Relative humidity and ambient temperature, in this analysis, have very little effect in determining the inherent target/background contrast radiance. Based on an AFWAL analysis of the data (15), the following figure of merit is also postulated:

$$M = T^n * F^m * e^{-(k \times V_w)}$$

where V_w is the wind speed and k is an empirically determined constant.

Note that all of these forms for the performance figure of merit are based on an atmospheric radiation balance which is positive, i.e., that the target and backgrounds are receiving more radiation than they are emitting, or, at the very least, are in equilibrium. At night the solar flux is zero, and these formulations do not offer a practical means for predicting a relative system performance.

However, it seems obvious that a similar approach, using the AFATL target/background radiance data and a simple radiation model, would allow a formulation for nocturnal differential cooling to be deduced to give a night time figure of merit based on similar geophysical parameters. This aspect of sensor performance statistics and comparisons is left for a future study.

2.5 EO DATA BASE ANALYSIS

For each of the stations selected, the following information was available (either from observation or calculation) at three hour intervals for the three year period of record:

- Meteorological Observables (temperature, visibility, etc., as provided in the DATSAV Manual (16)).
- Transmission (visible, 3-5 um, 8-12 um)
- Solar Flux
- Figures of Merit (each of six)

Results of this study are based on the statistics of occurrence at each location for these parameters, and the correlations among them.

SECTION 3

ASSESSING THE DATA

3.1 ADEQUACY OF A THREE YEAR DATA SET

The normal rule of thumb for developing climatologies suggests that a minimum of fifteen years of data is required. It is the eventual goal of this effort to assess such periods, but computer limitations currently make the quantity of data associated with this period of record prohibitive. A three year period was chosen as a compromise between computer resources and sample depth.

The drawbacks to such a compromise are that a "run" of good or bad weather over a few years could bias the projected climatology of a region, thus limiting the utility of studies based thereon. Hence, to assess the magnitude of this problem, some comparisons were made.

Figures 3a and 3b show a comparison of transmission over a 4 km path, calculated for visible, 3-5 um, and 8-12 um bands, for 1977 and for the years 1977-1979. The horizontal axis "percentile occurrence" refers to the cumulative frequency of occurrence for transmission less than or equal to that plotted. Thus, for the 1977 data, 70 percent of the 8-12 um transmission values calculated were less than or equal to 0.6. As can be seen, the results are quite close.

There is no direct way of determining the climatological representativeness of these three years for parameters such as particle size distributions, or other optical properties of the atmosphere. We can assume, however, that the optical parameters are, in some sense, associated with the standard weather variables. By showing that these variables were "typical" compared with the longer term climatology, one can hypothesize,

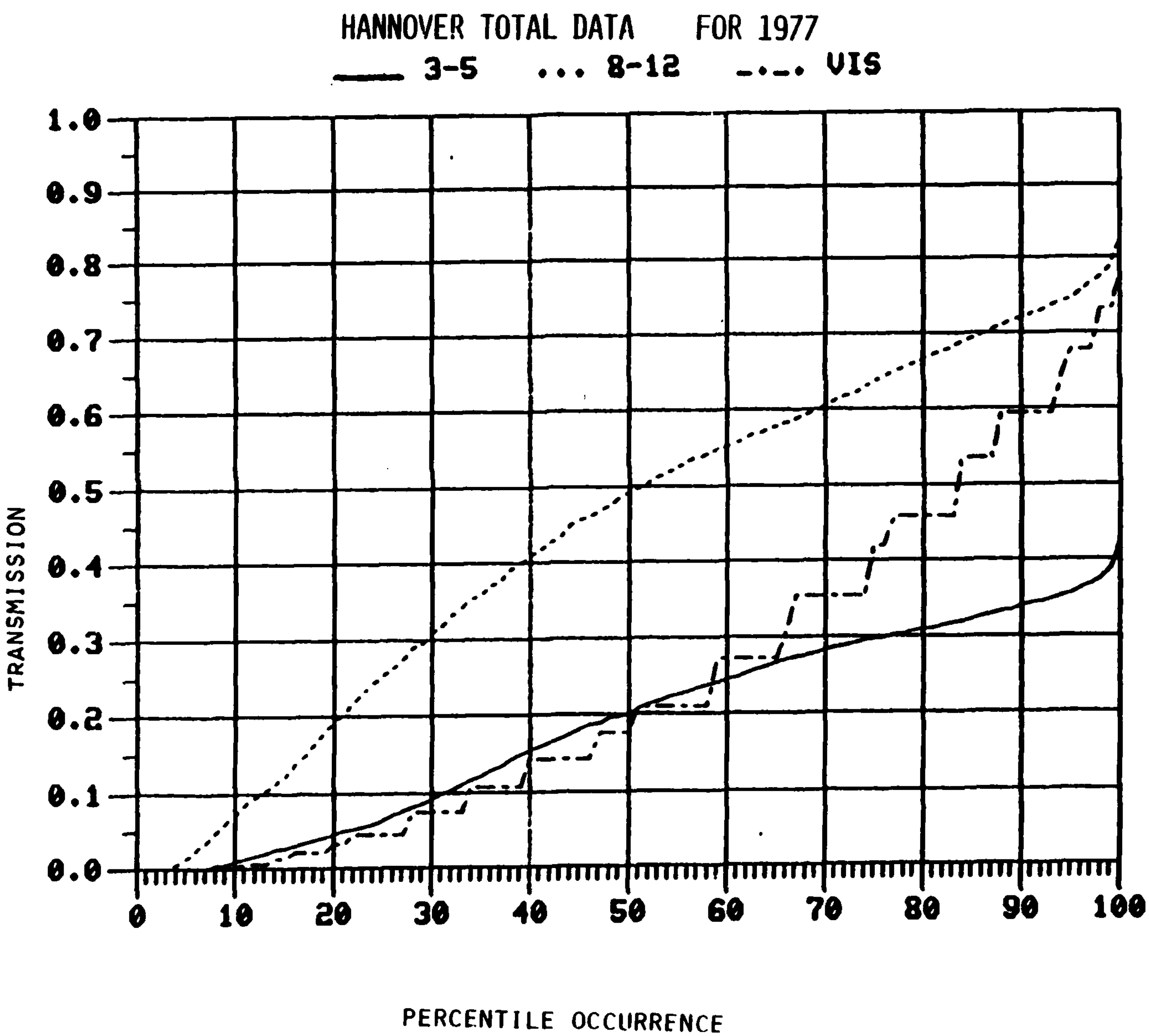


Figure 3a. Four km Transmission Occurrence Statistics for 1977.

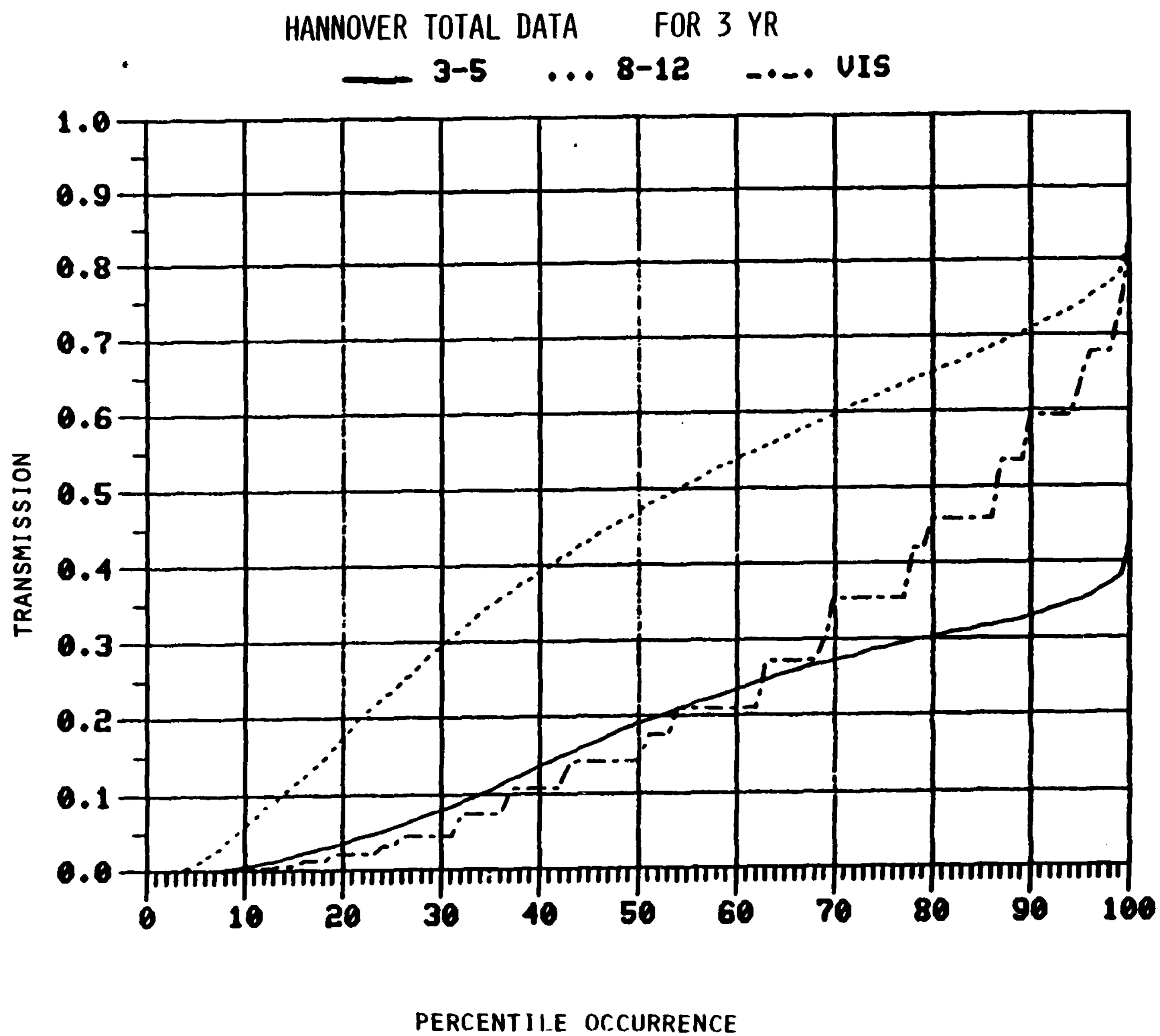


Figure 3b. Four km Transmission Occurrence Statistics for Three Years 1977-1979.

with at least somewhat greater confidence, that the optical parameter "climatology" and the figure of merit "climatology" should also be typical in a climatological sense.

To confirm that the 1977-1979 period of record is representative, several standard climatological categories were examined for three stations in Germany. Figure 4 is a plot of frequency of occurrence for weather at Hannover in the category of less than 300 ft ceilings and/or visibility less than 1 mile. Three times of day (Greenwich Mean Time (GMT)) are plotted: Morning (0600), noon (1200), and evening (1800) for all months. A comparison of the ten year climate summaries (17) and the 1977-79 data set shows generally good agreement. The exception is morning and evening weather in February. Our data set shows about 10 percent more low ceilings and/or low visibilities than is usually observed in February. Similarly, the June months in our data set had a higher frequency of "bad" weather. On the other hand November tends to reflect better than normal weather with less frequency of low ceilings and/or visibilities.

Figure 5 depicts the frequency of ceilings less than 1,500 ft and/or visibilities less than 3 miles for Hannover. Here the similarity of the three year data set to the climatology is quite good. The only notable exception is again November. A year by year inspection of the November data showed that 1977 had exceptionally good weather, while 1978 was an average year. November 1979 fell between 1977 and 1978; it had better than average weather, but not as good as 1977.

Similar comparisons were done for all the stations which were used in this analysis. Figure 6, for example, compares the frequency of ceilings less than 1,500 ft and/or visibilities less than 3 miles for Giessen. There are no significant deviations in the curves for the three year data set as compared to the long term climatology. Figure 7 is an example of another weather category used in the comparisons. The frequency of the

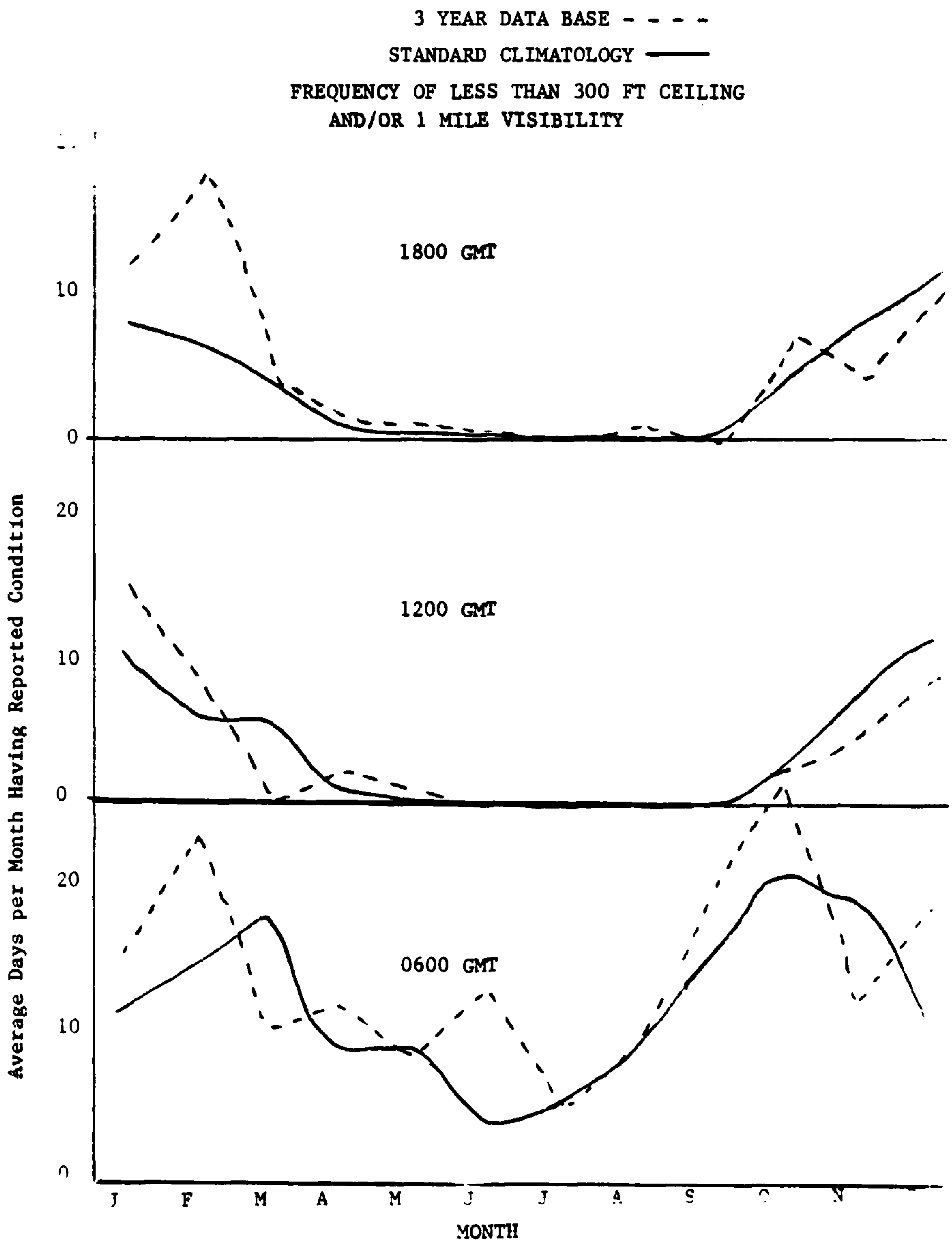


Figure 4. Hannover Ceiling & Visibility Occurrence Statistics: Less Than 300 ft Ceiling and/or 1 Mile Visibility.

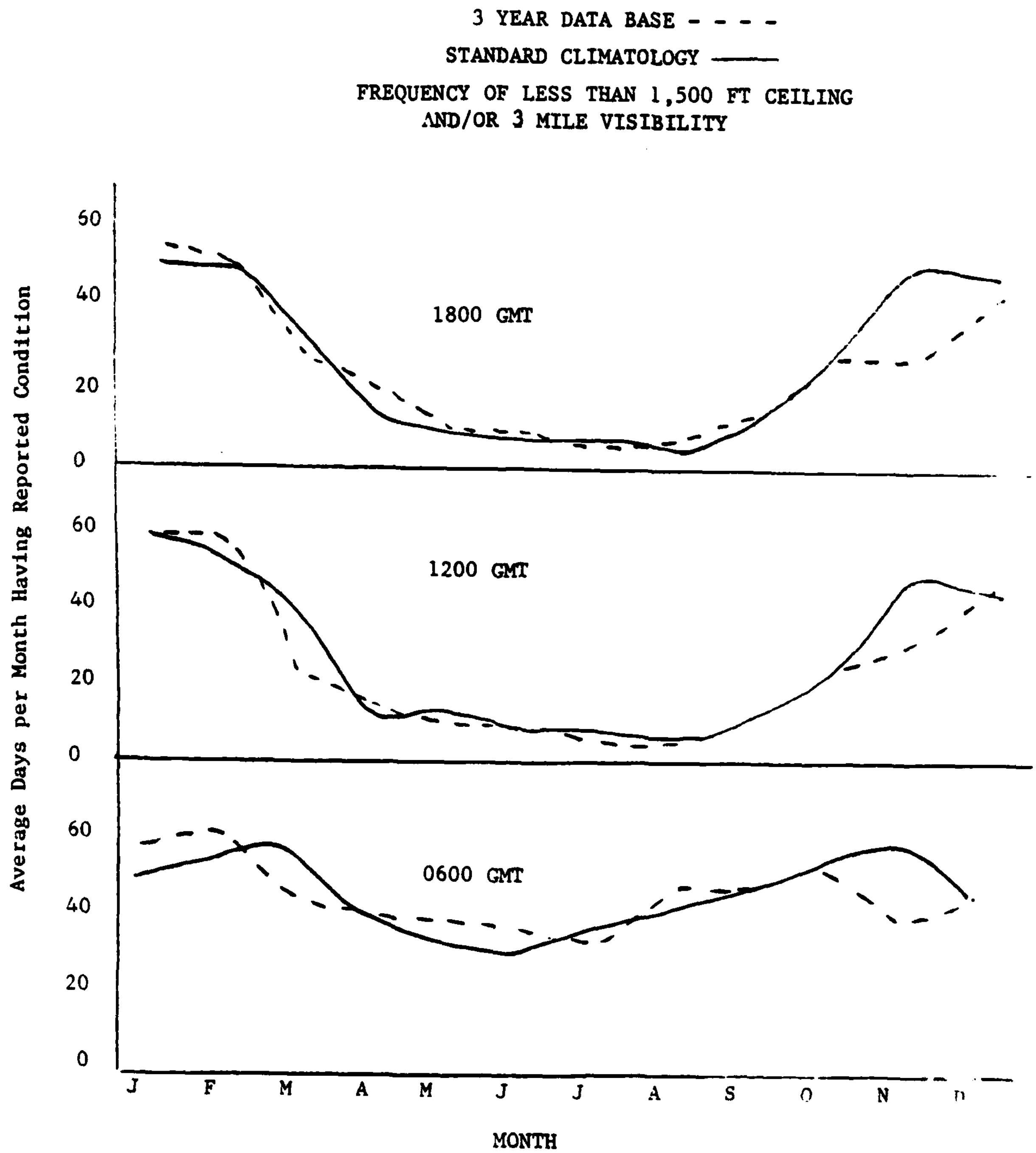


Figure 5. Hannover Ceiling & Visibility Occurrence Statistics: Less Than 1,500 ft Ceiling and/or 3 Mile Visibility.

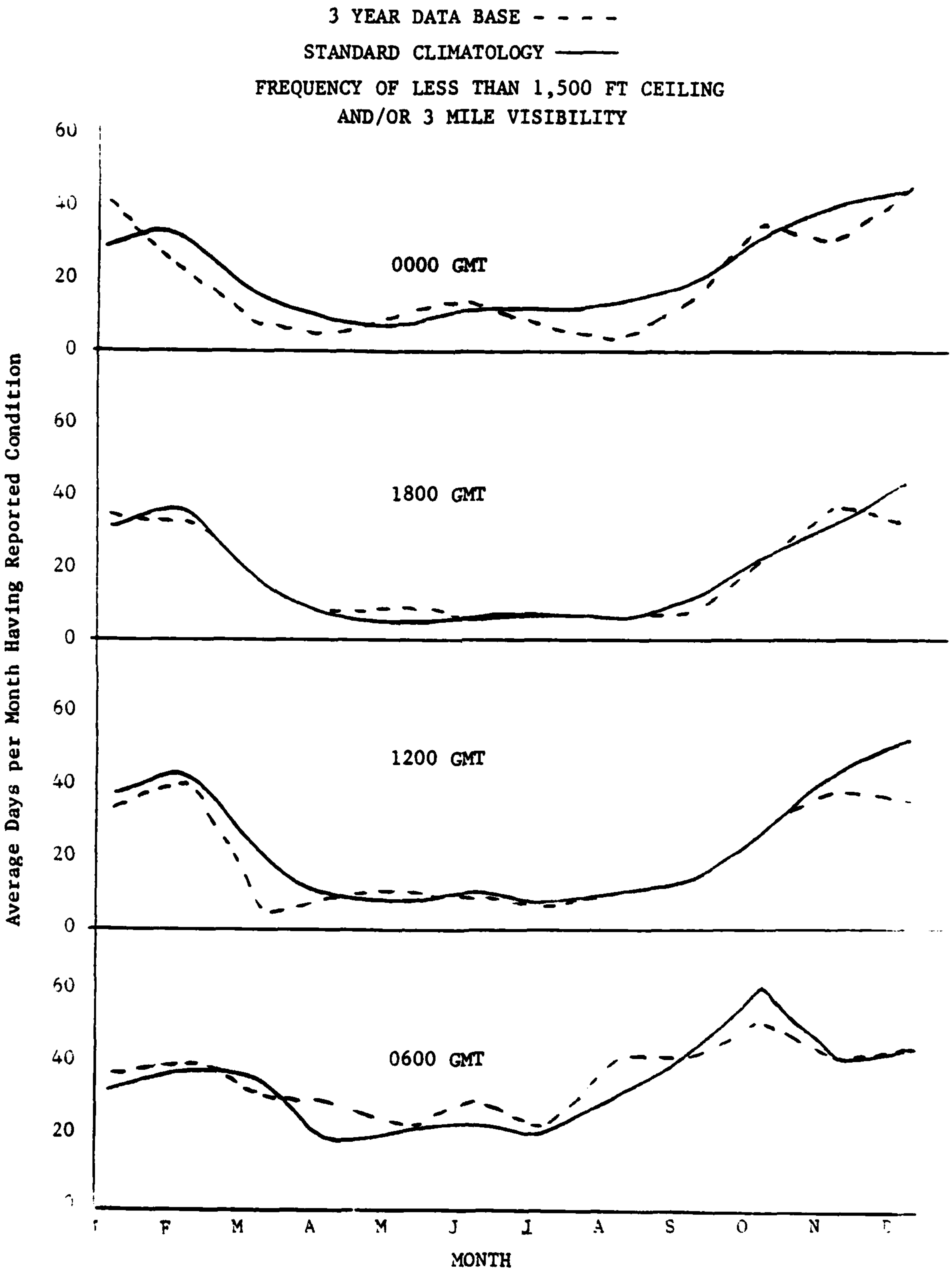


Figure 6. Giessen Ceiling & Visibility Occurrence Statistics: Less Than 1,500 ft Ceiling and/or 3 Mile Visibility.

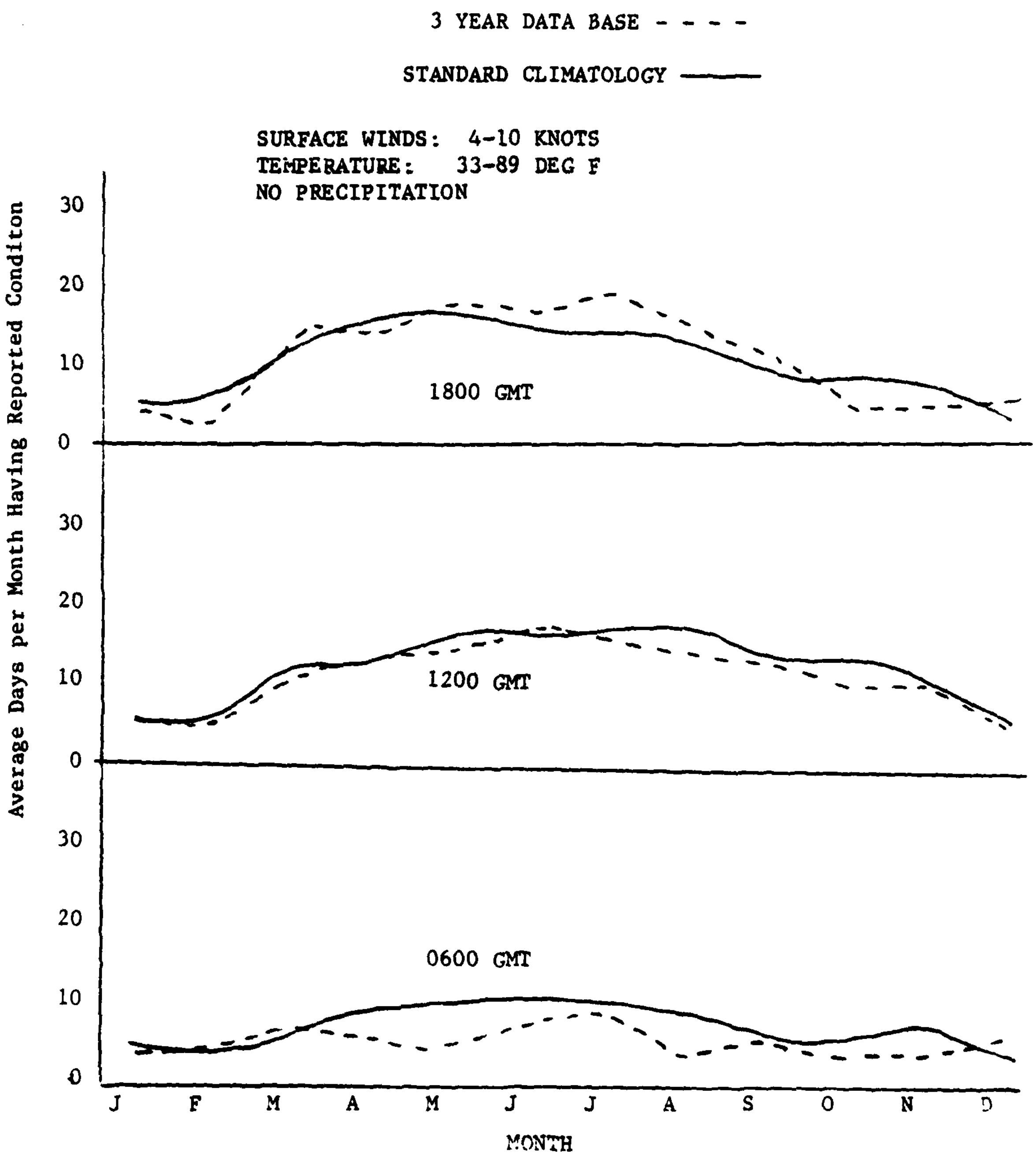


Figure 7. Giessen Simultaneous Wind Speed, Temperature, and Precipitation Condition Occurrence Statistics.

combination category of winds 4 to 10 knots, temperatures 33 to 89 degrees Fahrenheit (°F), and no precipitation is given for Stuttgart. Again no notable discrepancies were observed. The figure emphasizes the similarity of the period 1977 to 1979 to the long term climate of Germany.

3.2 OBSERVATION DENSITY

Very few European observations were missing from the data set. The exceptions were as follows:

- Berlin, Giessen, Hof, and Stuttgart had about 25 observations at each time of day during January 1977, rather than the expected 29-31.

- Giessen had few, if any, observations reported for 2100, 0000, and 0300 hours during October and November 1978, and only about 20 observations in each of these time periods during December of that year, rather than the expected 30-31.

- Hannover had only 27 observations per time period during January 1979, instead of the expected 31.

- Hof, Schleswig, and Stuttgart had only 24-28 observations per time period during January 1978, instead of the expected 31.

- Hof had only about 24 observations per time period during January 1979, instead of the expected 31.

On the other hand, the Near East stations are subject to considerable variation. While the record of Amman and Kuwait is generally good, other stations, such as Sana, Yemen, have as few as two observations in some months.

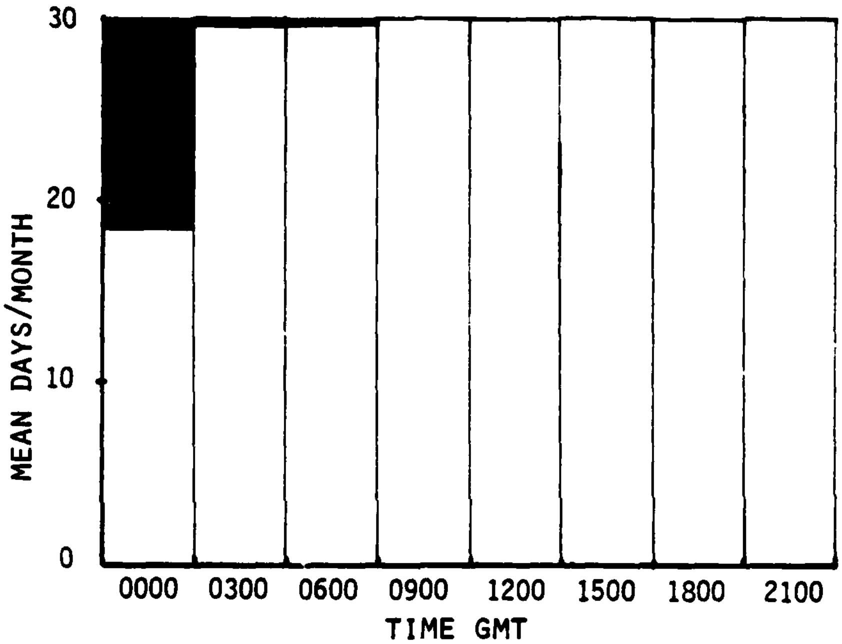
3.2.1 Observation Density for Transmission Calculations

The total observation set was not usable for this analysis. Certain parameters must be present to calculate transmission values. These parameters are pressure, temperature, dew point temperature, visibility, and present weather code (for precipitation determination). A missing pressure value was not considered to be a significant problem. While transmission is sensitive to pressure, the maximum real world variation in surface pressure is on the order of a few percent. Thus, when pressure was unavailable, a standard atmosphere value (for the station altitude) or the previously reported value could be utilized. The possible variation in the other parameters, however, was enough so that when one or more of them was missing, the observation had to be discarded.

As a result, the effective observation density was smaller than that in the basic data set. In Europe, there was generally little loss; observations there were relatively complete, except at 0000 hours GMT. In the Near East, however, there was a greater problem. This is illustrated by Figures 8a and 8b.

As the bar chart for Hannover (Figure 8a) shows, there were approximately 30 days/month of observations at all times of day. Except for observations at 0000 hours, almost all of these were suitable for transmission calculations. A number of observations at 0000 hours were unsuitable, though some of this loss was due to a program problem that was found and resolved in a more recent analysis.

The chart for Amman (Figure 8b) shows more variation in the observation density and, overall, a smaller fraction of the total data set suitable for transmission calculations.



HANNOVER DATA

UPPER BAR: TOTAL DATA SET
LOWER BAR: DATA SUITABLE FOR TRANSMISSION CALCULATIONS

OBSERVATION DENSITY (MEAN DAYS/MONTH)

Figure 8a. Observation Density: Hannover 1977-1979.

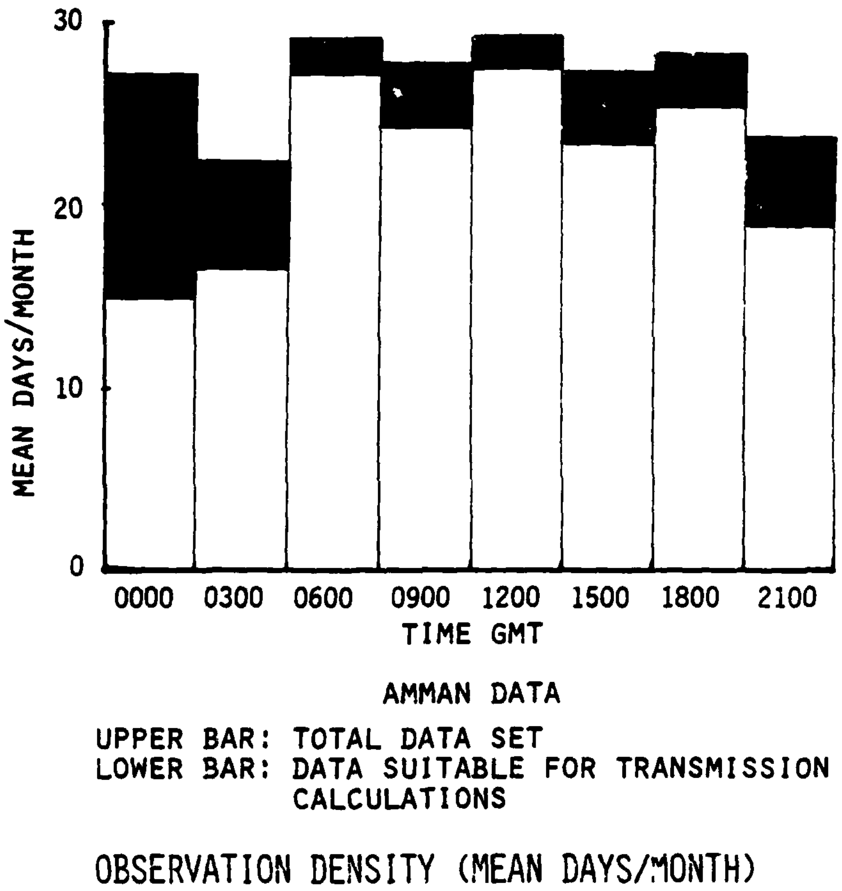


Figure 8b. Observation Density: Amman 1977-1979.

3.3 USAFETAC QUALITY ASSURANCE PROCEDURES

As part of the data archival process, USAFETAC makes a few first-order quality checks to identify spurious data. These checks include making sure that the air temperature equals or exceeds the dew point temperature and that wind speeds do not exceed wind gusts. No occurrences of such problems were found in the data base.

3.4 ADDITIONAL QUALITY ASSURANCE PROCEDURES

A variety of automated tests were developed to examine this data for more sophisticated errors. The rate of obvious inconsistencies was quite low. In the 2884 observation Hof 1977 data set, for example, one case of sky cover less than cloud base cover was found, 16 cases of incorrect merged coding of present weather in a "merged" observation type, and 1 case of an incorrect coding of cloud height (a code value of 55 for WMO Code 1677).

Many more cloud height (WMO Code 1677) errors appeared in the Near East data set. For example, Amman had 21 such errors in 1978 and 57 in 1979. As was the case in Germany, an unused (and therefore meaningless) 50-series code (typically 51) was reported.

In conclusion, the European portion of the data base is quite "clean" and suitable for use. Quality checking of the Near Eastern portion is less incomplete, but seems to indicate more variation in data quality.

SECTION 4

STATISTICAL RESULTS

Frequency distributions, i.e., climatologies, for most standard weather variables, can be found in a number of publications (e.g., (4,17)). The climatological distribution of computed variables associated with EO system performance (e.g., atmospheric transmission or solar flux) are far less common. Developing such statistics was one of the objectives of this study. While hundreds of plots could be made illustrating various statistical aspects of this data base, only a representative few will be presented here.

4.1 FREQUENCY DISTRIBUTIONS

Of fundamental interest are frequency of occurrence of transmission, solar flux, and the figures of merit described in Section 2.

Various segments of the data are presented. The following definitions apply:

SUB-GROUP	DEFINITION
WINTER	December, January, February
SPRING	March, April, May
SUMMER	June, July, August
AUTUMN	September, October, November
NIGHT	0000 Hours GMT
DAWN	0600 Hours GMT
MID-DAY	1200 Hours GMT
EVENING	1800 Hours GMT

Figure 9 shows 4 km transmission in the three wave bands of interest for Hannover, Germany, based on all observations available for three years. Note that 8-12 um transmission is substantially better than that in the other two bands. As a geographic comparison, Figures 10, 11, 12, and 13 show similar plots for Giessen, Stuttgart, Amman, and Kuwait. Note that Giessen and Stuttgart are significantly better than Hannover, and that, as might be expected, Amman and Kuwait are best of all. This reflects a somewhat improved "transmission climate" in southern Germany, and both a better "climate" and somewhat different aerosol assumptions (rural versus maritime) in the Near East. The difference in aerosol assumptions may also explain the difference in relative visible versus 3-5 um transmission levels between the German and Near East Stations.

Descriptions of each standard aerosol model provided by LOWTRAN (Rural, Urban, Maritime) are given in the LOWTRAN 5 Manual (7). In general, for the same visibility, maritime aerosols have higher extinction than rural aerosols in the IR for relative humidity values of 80 percent or more.

Focusing upon the Hannover data, various segments of this data may differ significantly. Figures 14, 15, 16, and 17 illustrate the percentile occurrence of transmission at dawn for each season. For atmospheric transmission in the 8-12 um band, Autumn and Summer Dawn appear equally poor. Spring Dawn offers the best 8-12 um dawn transmission distribution, followed by Winter Dawn. In the visible and 3-5 um bands, dawn transmission in Winter is generally lower than in the Summer, rather than higher (as is the case in the other two bands). One possible explanation is that the more frequent occurence of higher absolute humidities in Summer affects the 8-12 um band more than the 3-5 um band, due to higher molecular absorption by water vapor in the 8-12 um band. On the other hand, aerosol extinction may affect the shorter wavelenghts to a larger degree. Since Winter in Europe is typically characterized by low visibility (i.e., high aerosol densities) and cool temperatures (i.e., low absolute humidities), the difference seems reasonable.

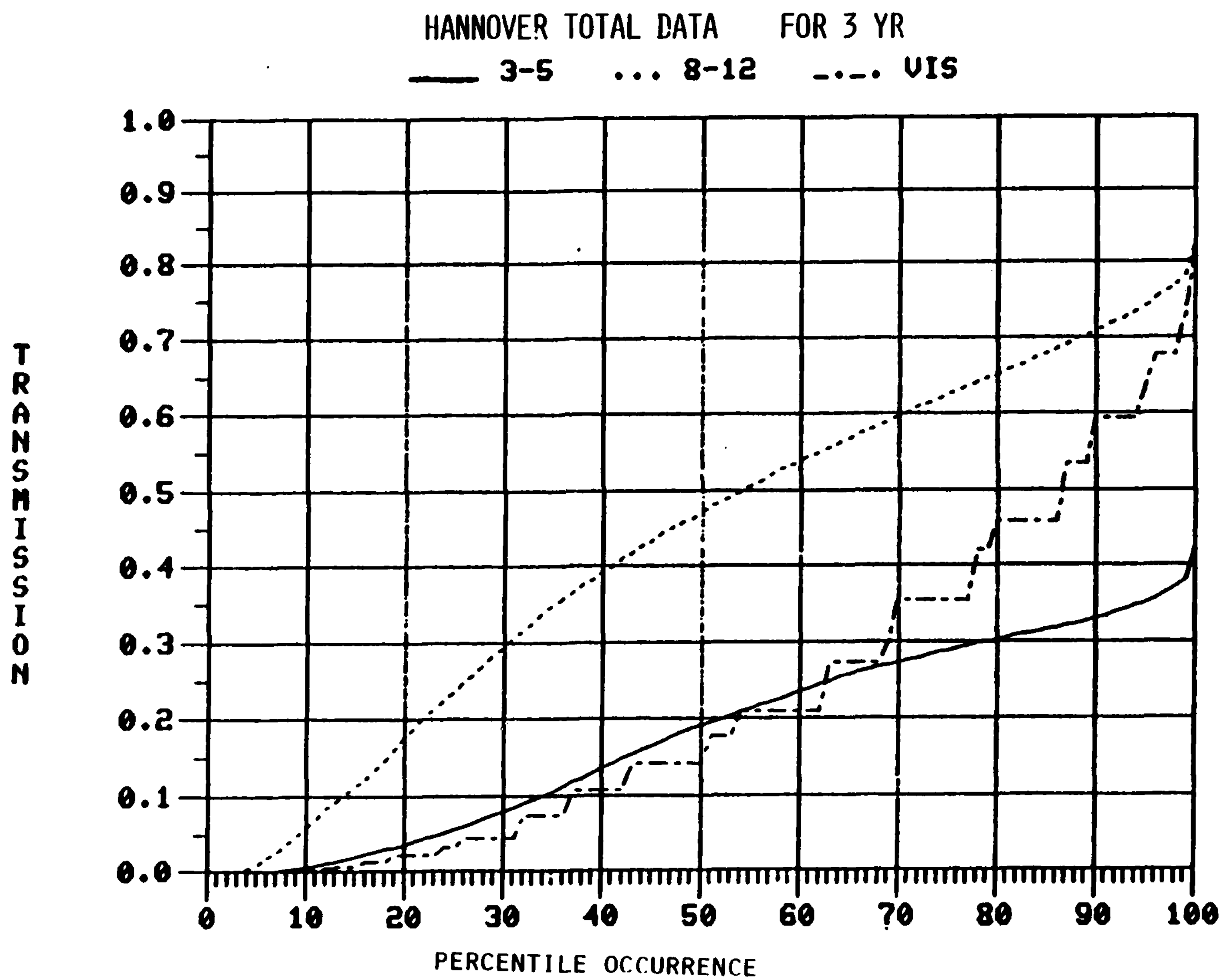


Figure 9. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Hannover, Year-Round Data.

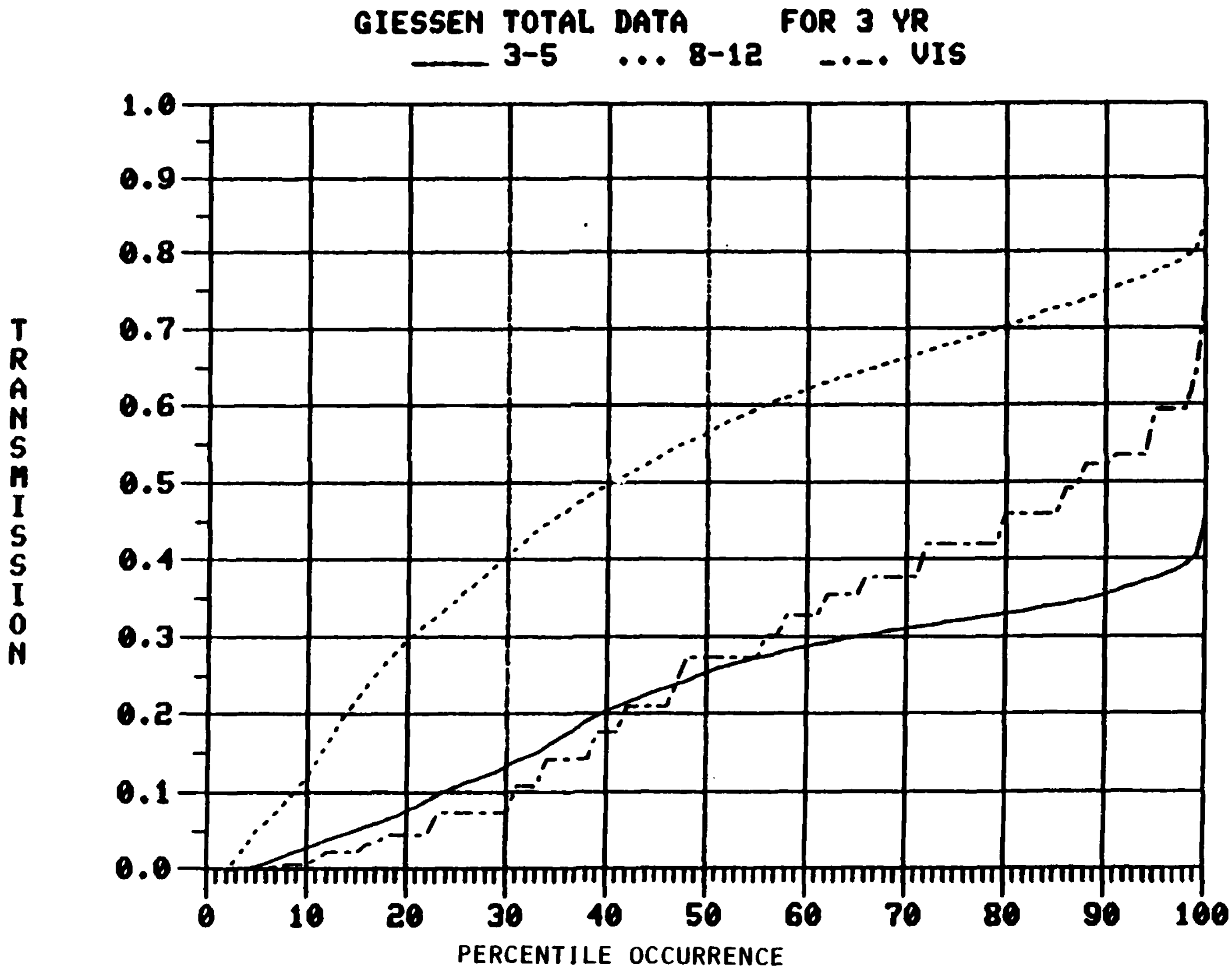


Figure 10. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Giessen, Year-Round Data.

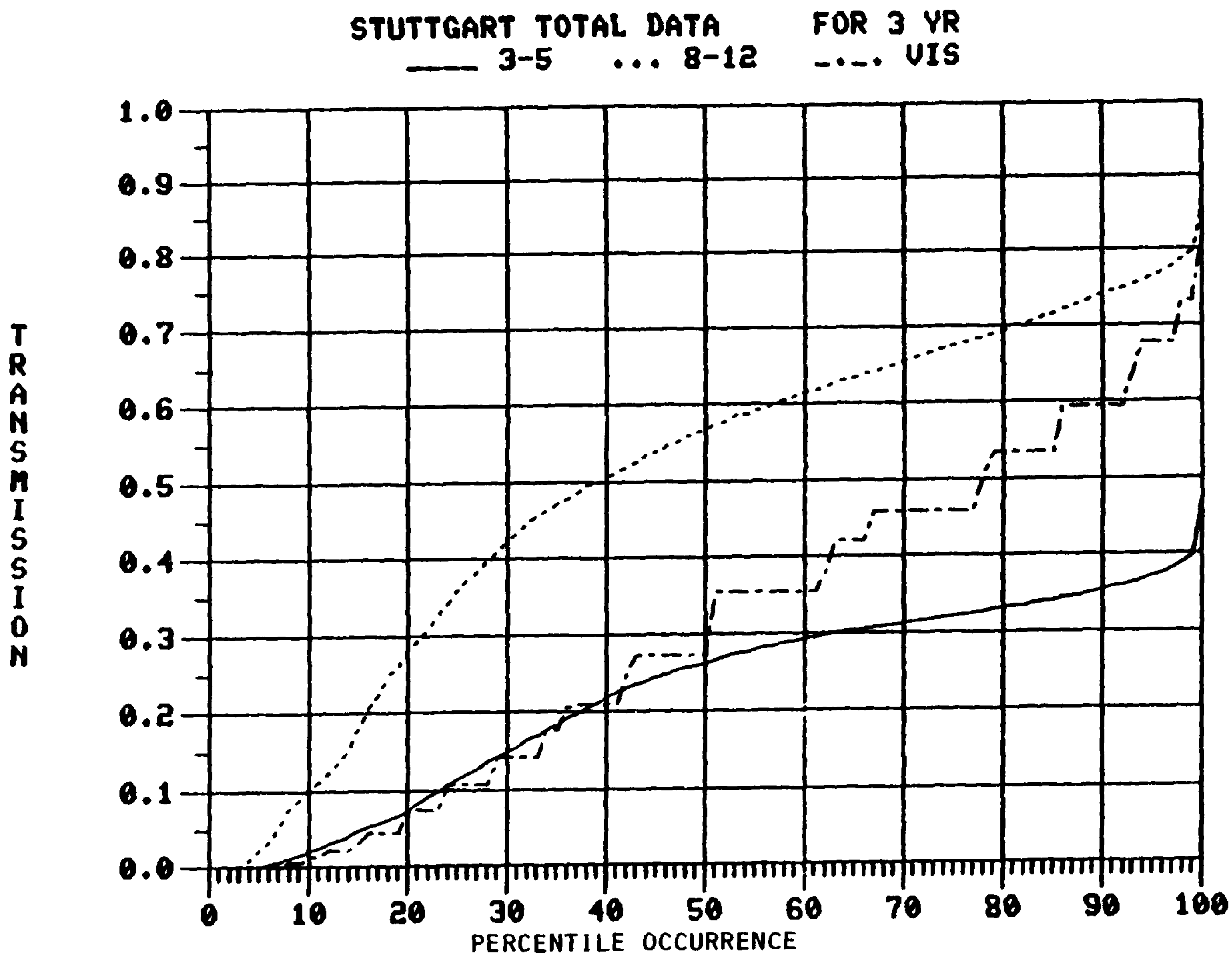


Figure 11. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Stuttgart, Year-Round Data.

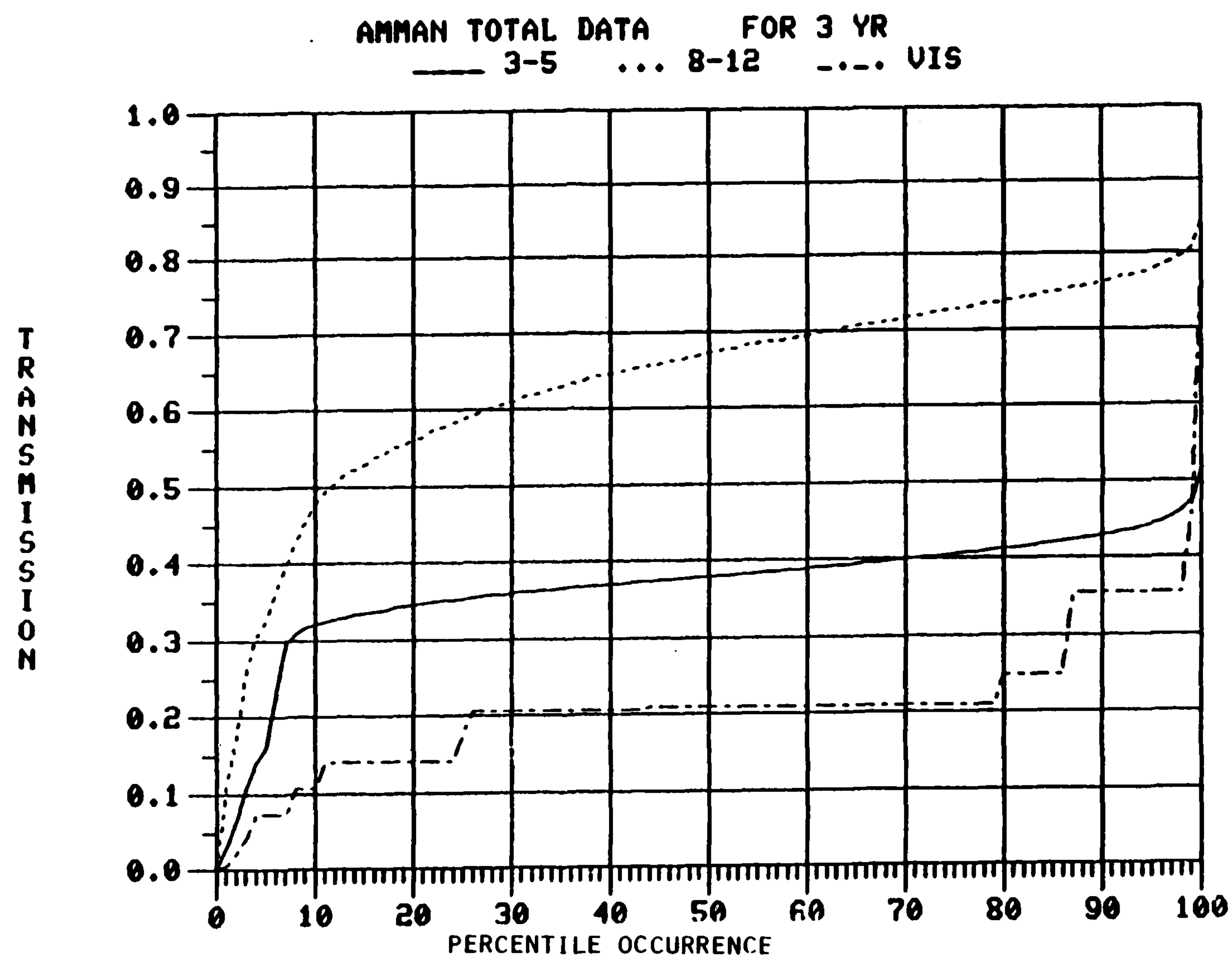


Figure 12. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Amman, Year-Round Data.

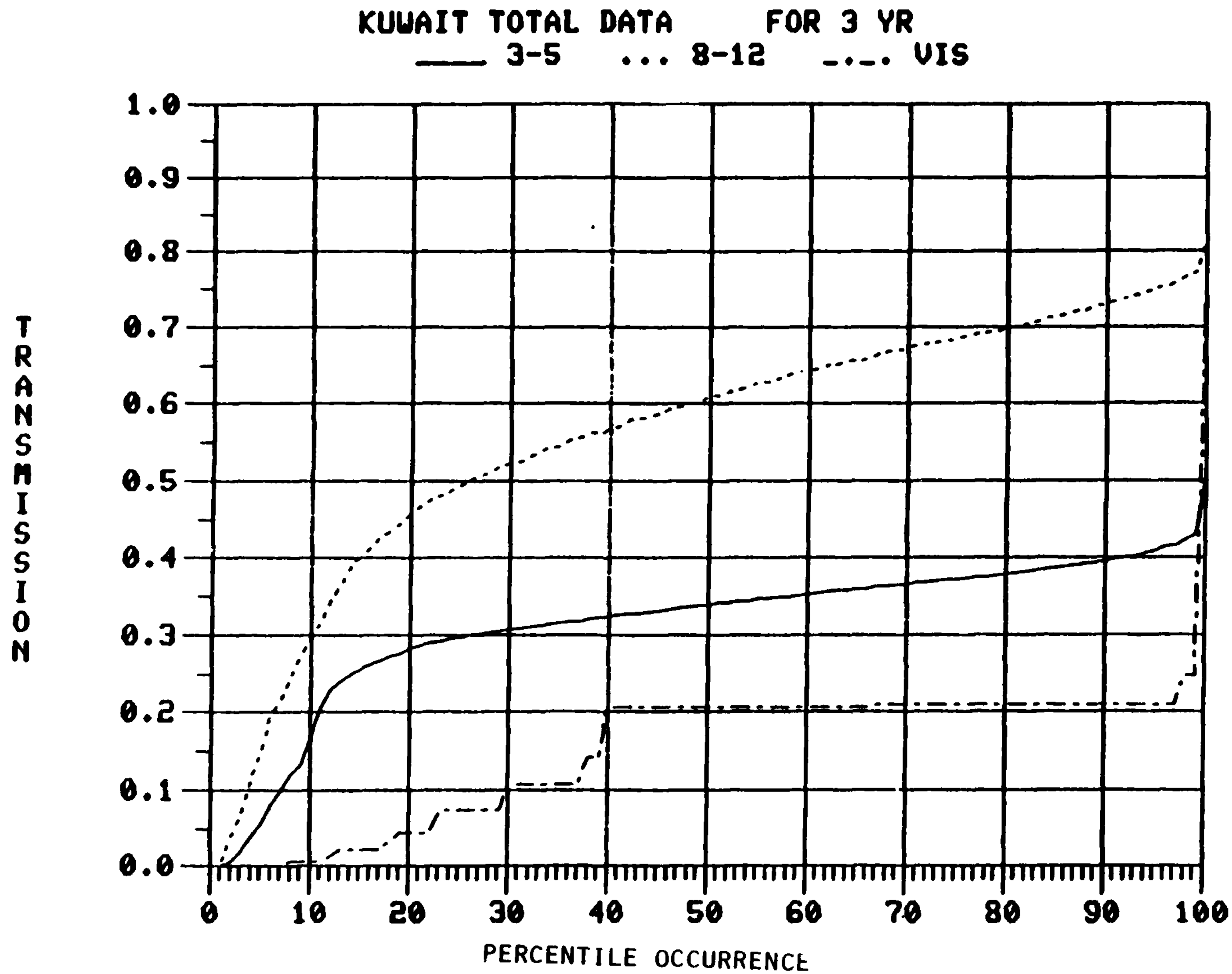


Figure 13. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Kuwait, Year-Round Data.

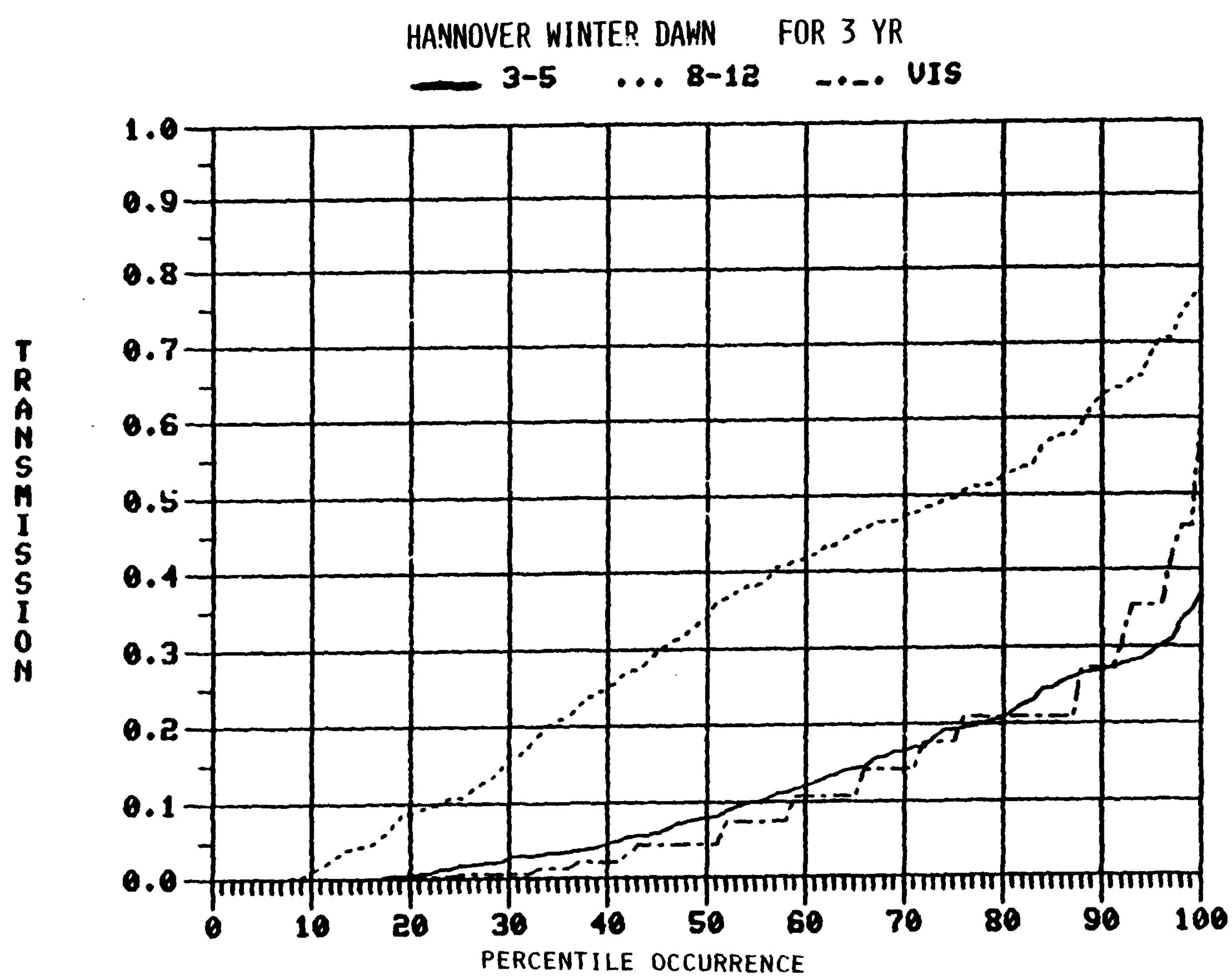


Figure 14. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Hannover, Winter Dawn Data.

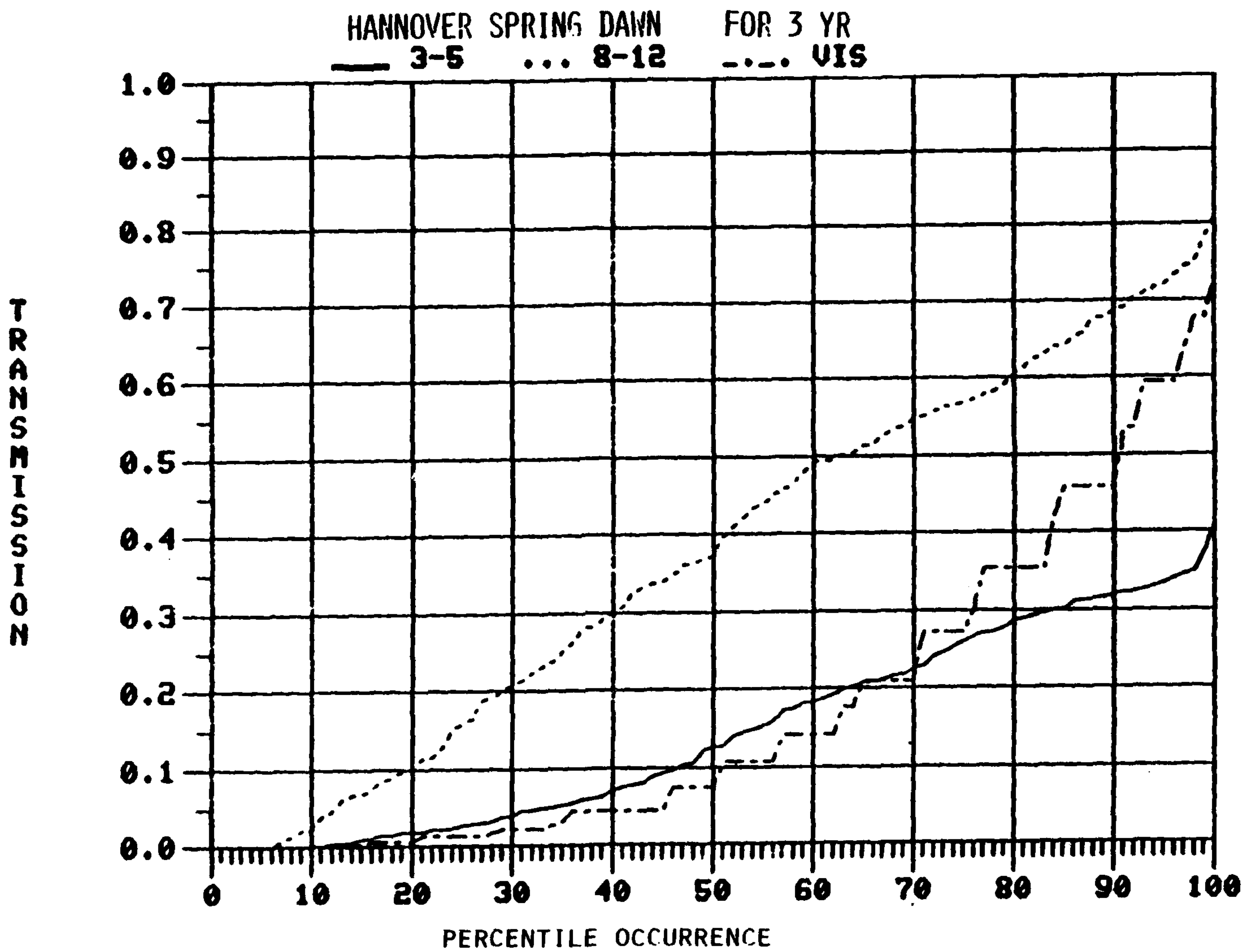


Figure 15. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Hannover, Spring Dawn Data.

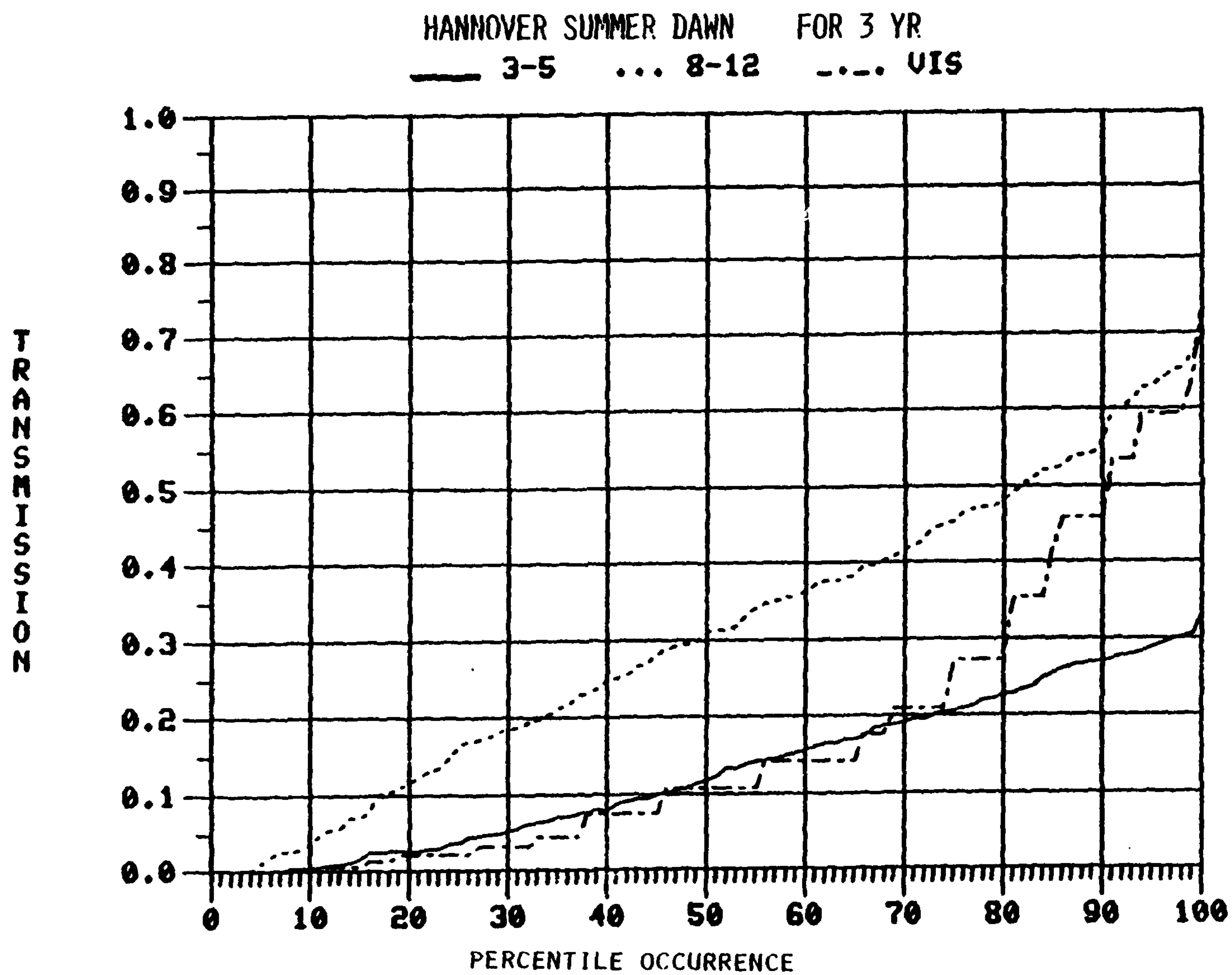


Figure 16. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Hannover, Summer Dawn Data.

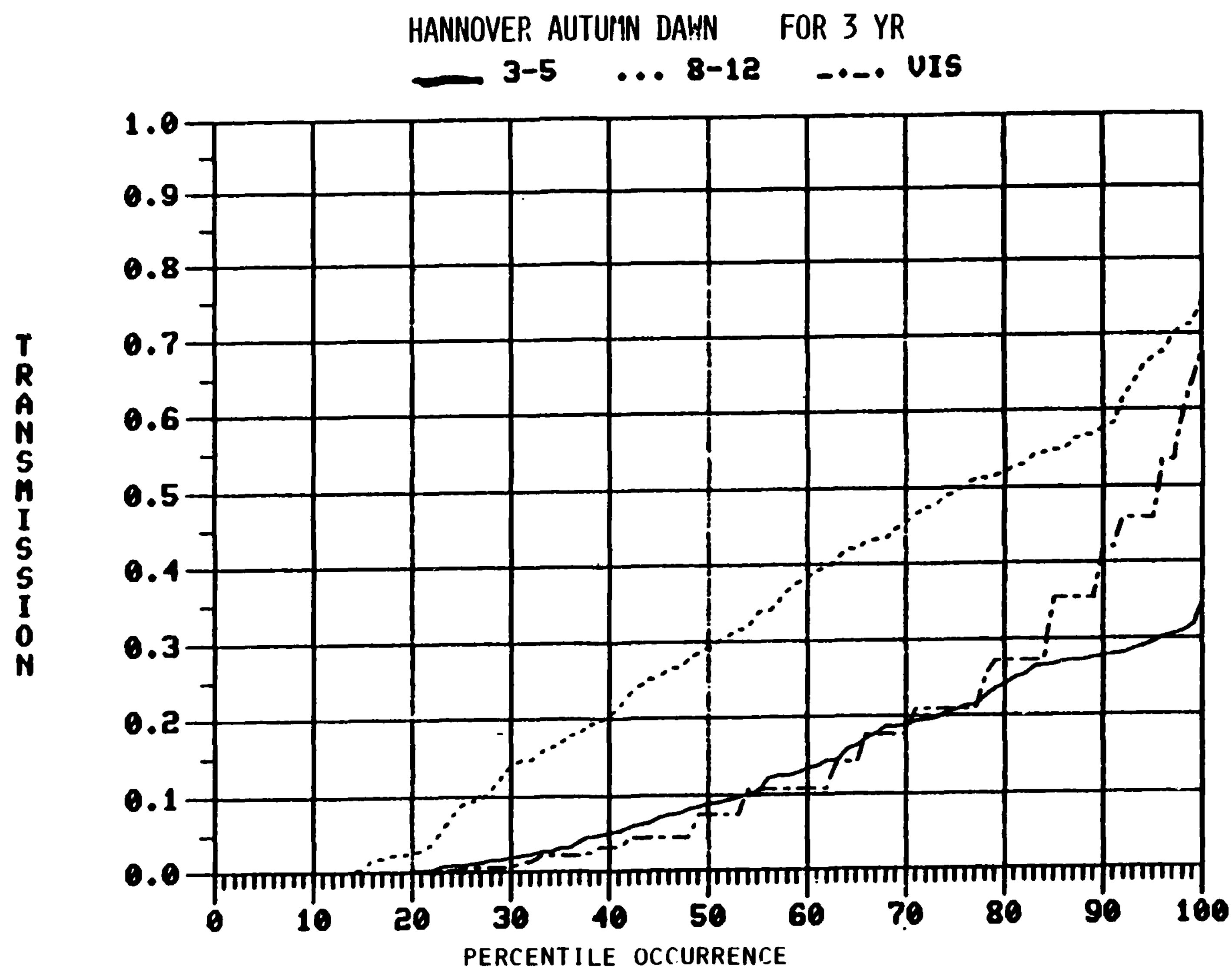


Figure 17. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Hannover, Autumn Dawn Data.

The springtime diurnal variation in transmission at Hannover is illustrated by Figures 18, 19, and 20, in combination with Figure 15 (Spring Dawn). Spring Dawn shows the lowest transmission values, while transmission seems best at mid-day and in the evening. Conditions at night worsen to resemble dawn levels. Night values should be used with caution. Because visibility is estimated by human observers, nightime reported visibility may as easily reflect the limitation imposed by lack of light as the limitation imposed by degraded atmospheric transmission (the factor assumed here). Nevertheless, intrinsically poor visibility and high relative humidity are often observed at night and in the morning, compared with greater visibilities and lower relative humidities during the day.

Figures 21, 22, 23, and 24 show occurrence of solar flux levels in Winter, Spring, Summer, and Autumn mid-day conditions respectively. Note that solar flux averages a factor of three higher in Summer than Winter, and that Spring flux levels are close to Summer ones, while Autumn flux levels are roughly between the two extremes.

The seasonal variation of solar flux observed at Hannover is primarily associated with the maximum solar height in each season. The sun elevation is highest in the Spring and Summer; therefore solar energy travels through a thinner layer of atmosphere and has an angle of incidence more closely normal to any horizontal surface. Thus, the mid-day solar flux, measured in power per unit horizontal area, is at a maximum when the sun is nearest the zenith. Other small differences between Autumn and Winter, and between Spring and Summer can be accounted for by the differences in cloud climatologies. Other German stations, not shown in this report, displayed similar characteristics.

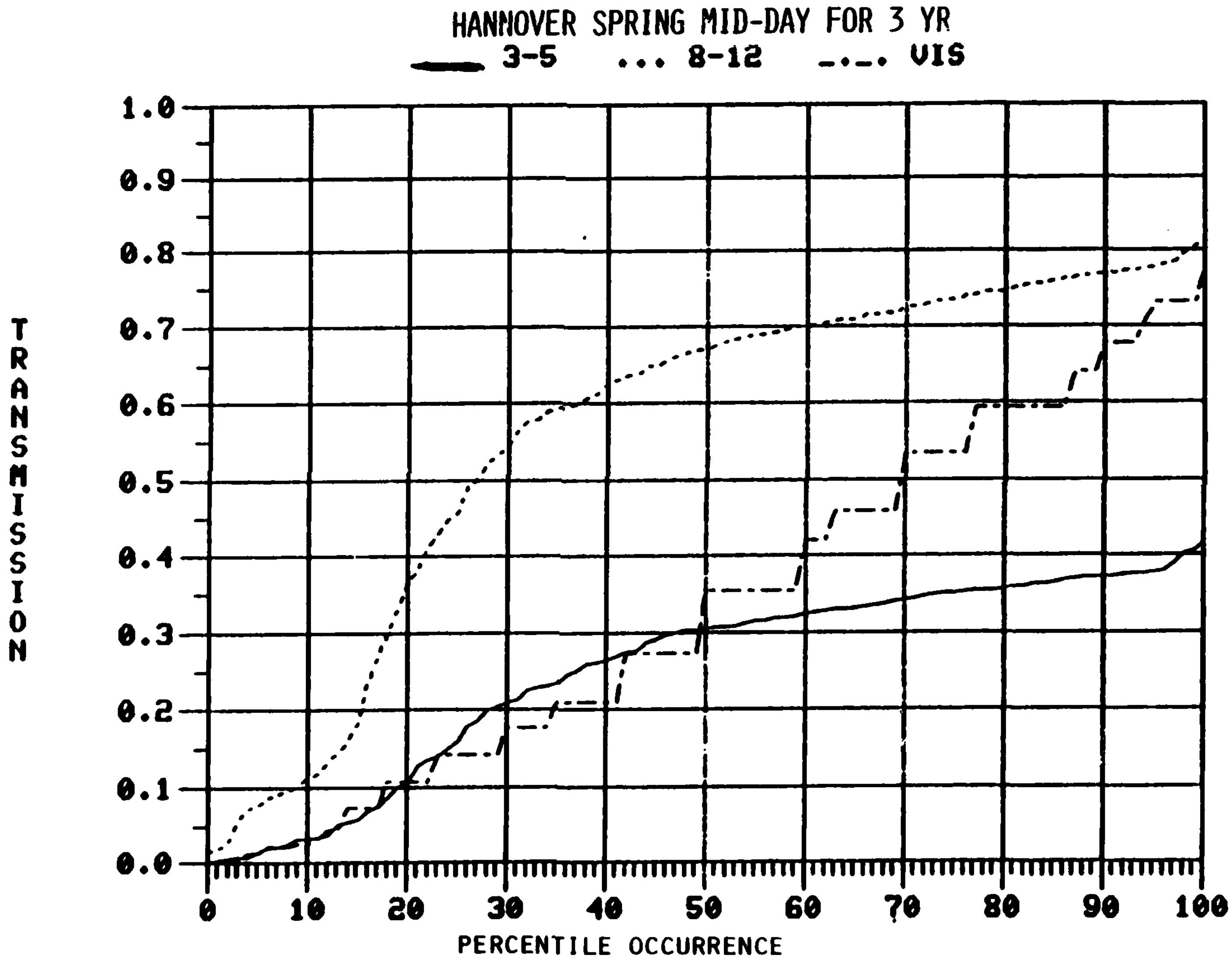


Figure 18. Visibile, 3-5, and 8-12 Micrometer 4 km Transmission: Hannover, Spring Mid-Day Data.

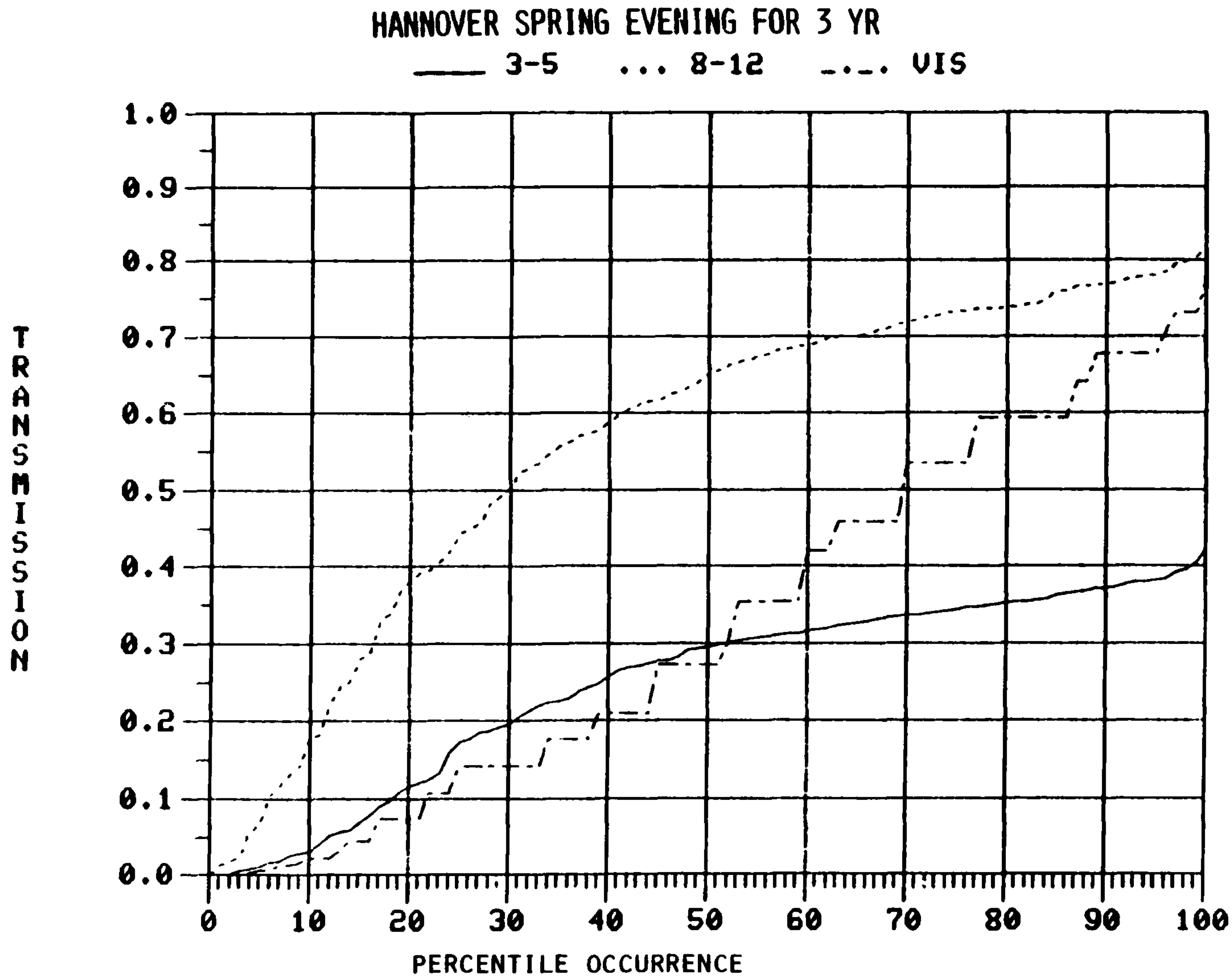


Figure 19. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Hannover, Spring Evening Data.

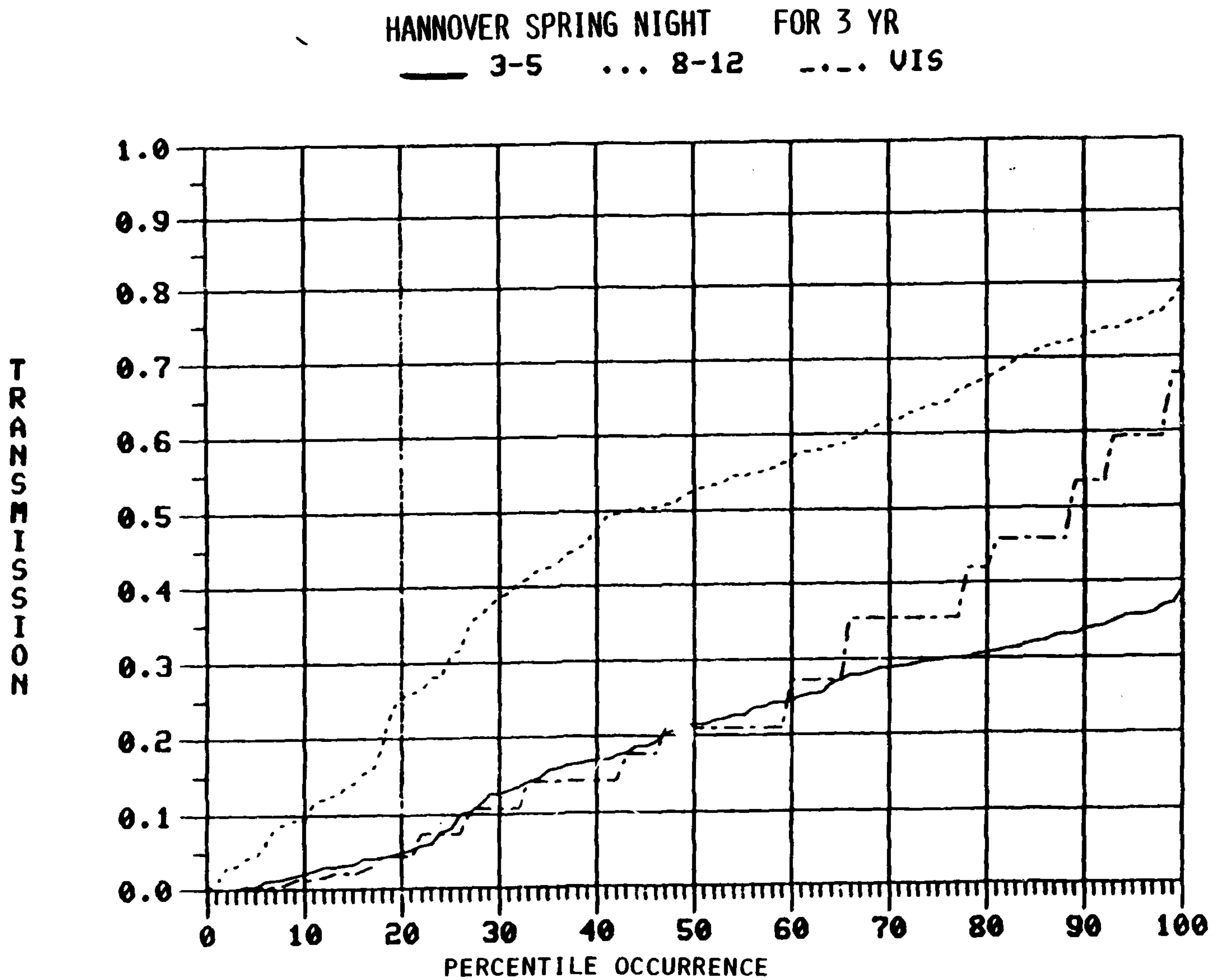


Figure 20. Visible, 3-5, and 8-12 Micrometer 4 km Transmission: Hannover, Spring Night Data.

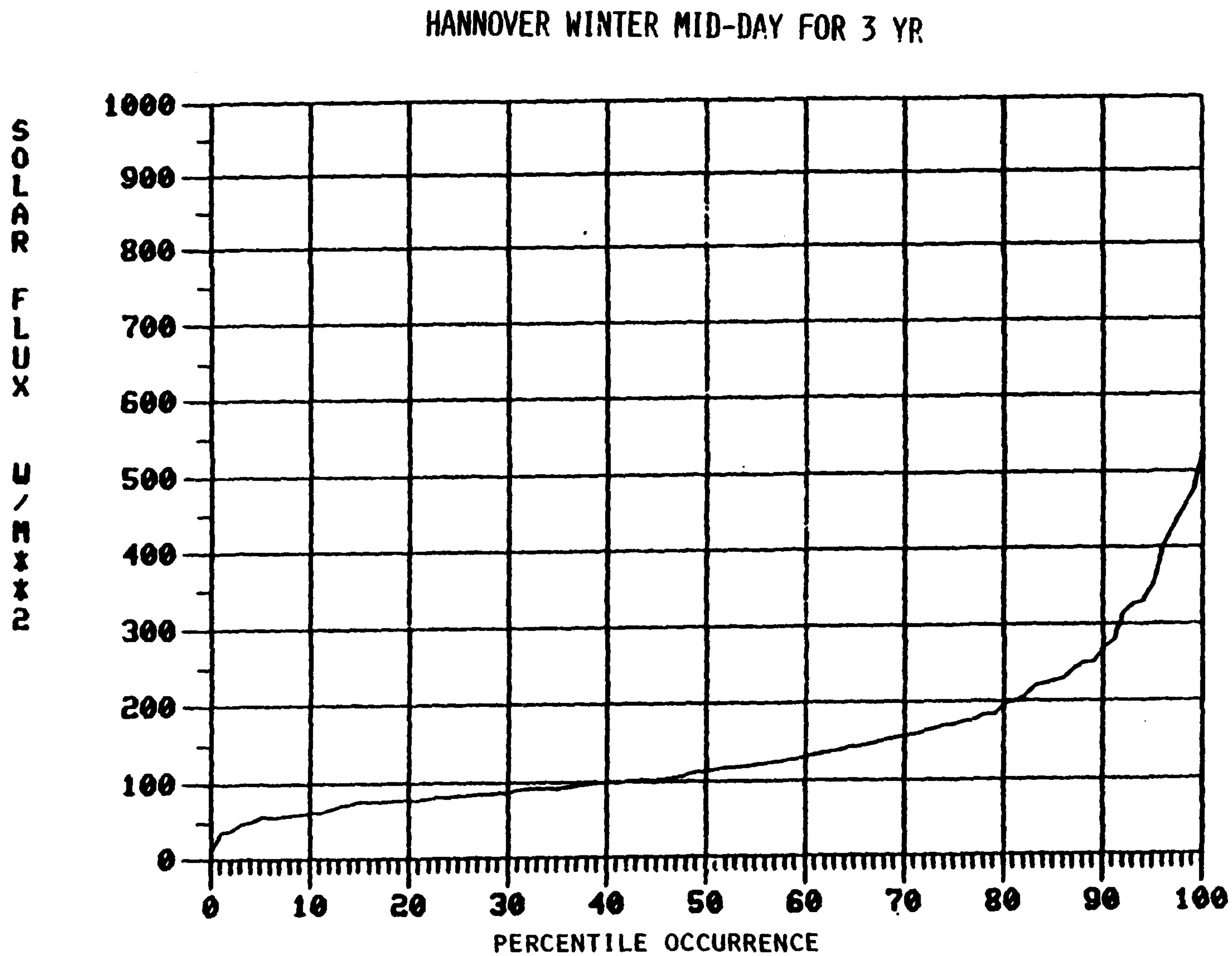


Figure 21. Hannover Winter Mid-Day Solar Flux.

HANNOVER SPRING MID-DAY FOR 3 YR

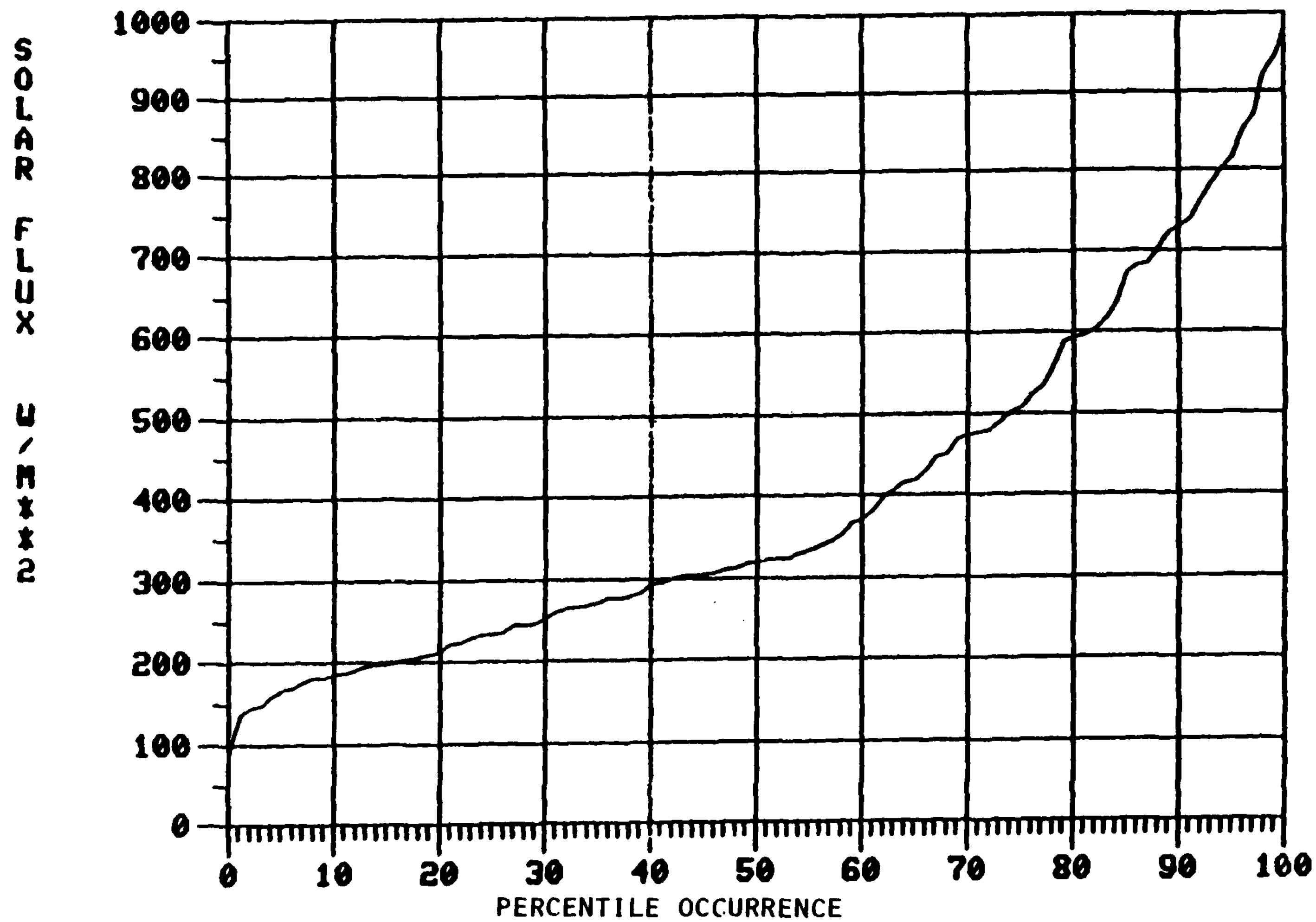


Figure 22. Hannover Spring Mid-Day Solar Flux.

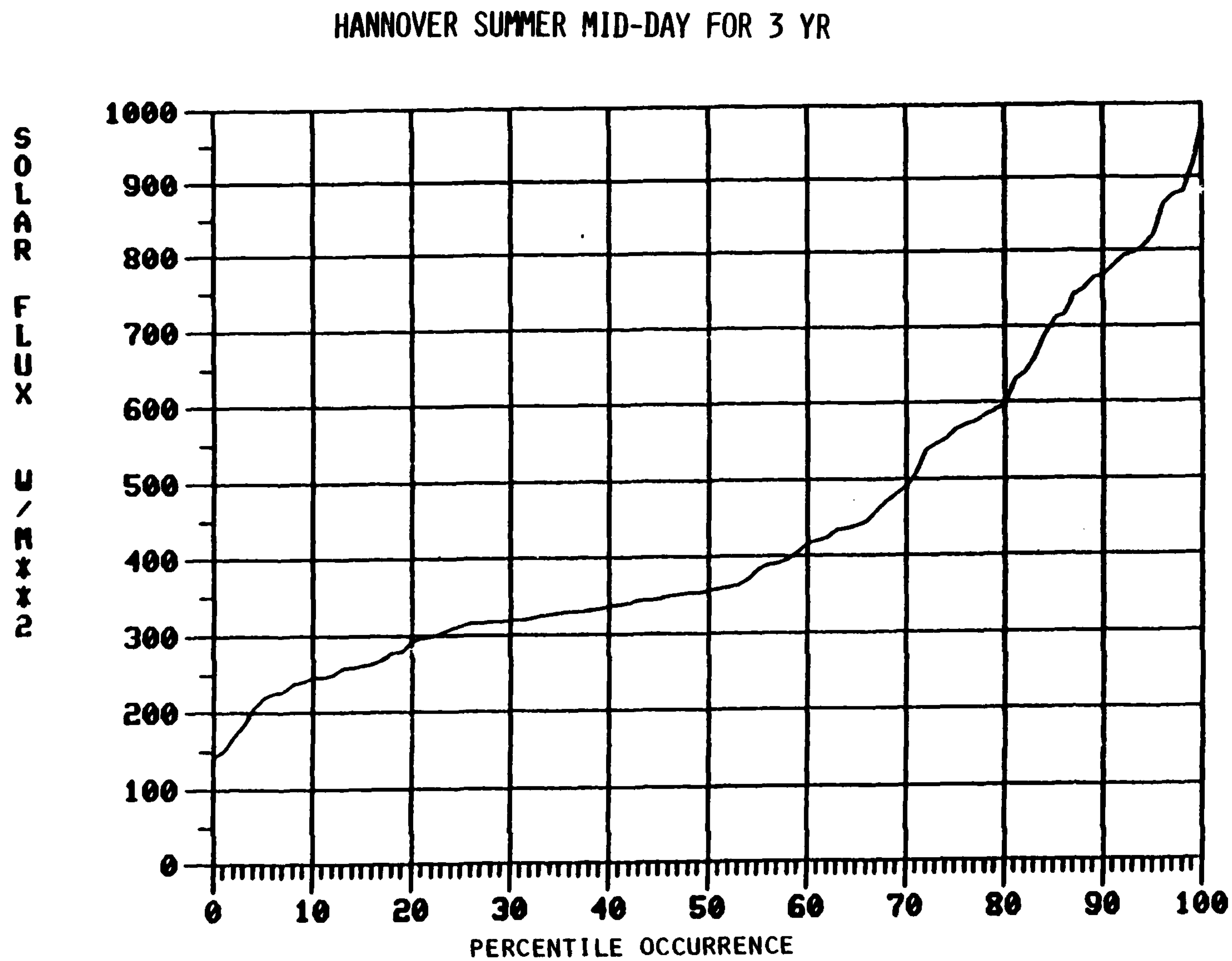


Figure 23. Hannover Summer Mid-Day Solar Flux.

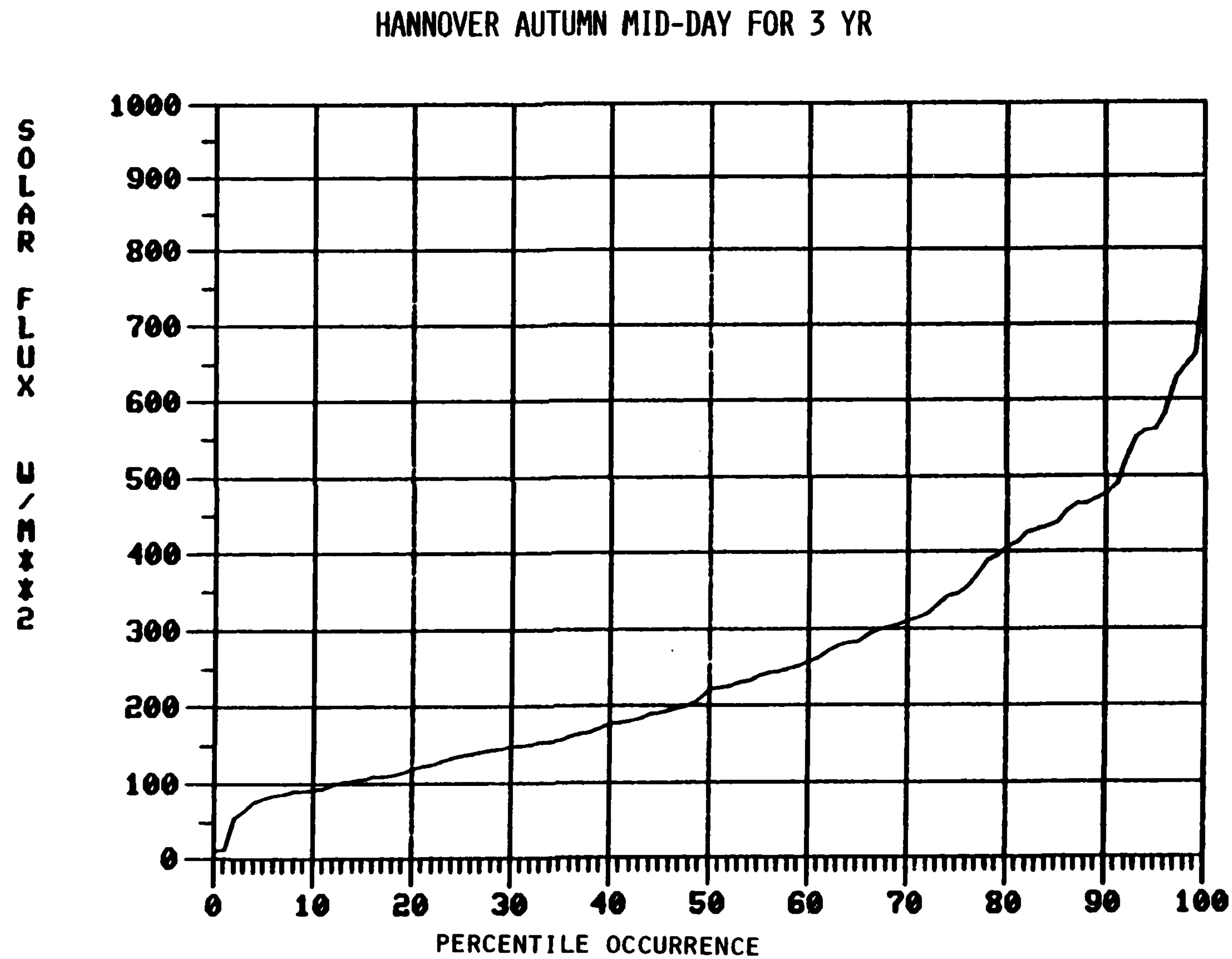


Figure 24. Hannover Autumn Mid-Day Solar Flux.

Figures 25, 26, 27,and 28 show the results of combining 8-12 um transmission and solar flux together into "Figures of Merit", as discussed in Section 2. Figure 25 is a simple comparison of Hannover Mid-Day 8-12 um transmission in Summer and in Winter. Figures 26-28 assume a figure of merit obtained by multiplying transmission times solar flux taken to the 1/2, 1, and 3/2 powers respectively, again comparing Summer and Winter mid-days.

Interpretation of these graphs yields some interesting conclusions. If transmission is assumed to be a valid figure of merit for some sensor scenario (as might be the case for thermal sensing of a hot exhaust pipe; Figure 25), and if it is known that, for example, the sensor performs adequately 80 percent of the time in Summer (corresponding to a 20 percentile occurrence and a transmission value of 0.475; Point A), then it will only operate about 40 percent of the time in the Winter (corresponding to the same transmission value; Point B).

By comparison, using Figure 27 with transmission times solar flux as the assumed figure of merit, if it is known that the sensor performs adequately 80 percent of the time in Summer (corresponding to a figure of merit value of 0.135), then it will only operate adequately about 13 percent of the time in the Winter (the fraction of the time corresponding to the same figure of merit value).

Of course, using a "figure of merit" is only a crude guess at the actual performance of a hypothetical EO system. Nevertheless, it illustrates an important point. If other factors, e.g., solar flux, play a significant role in system performance, they cannot be ignored in projecting operational effectiveness. This is particularly true where low values of both quantities may be correlated, thus consistently reinforcing each other, as transmission and solar flux are both reduced in poor weather.

M = TRANSMISSION

4 KM TRANSMISSION OCCURRENCE

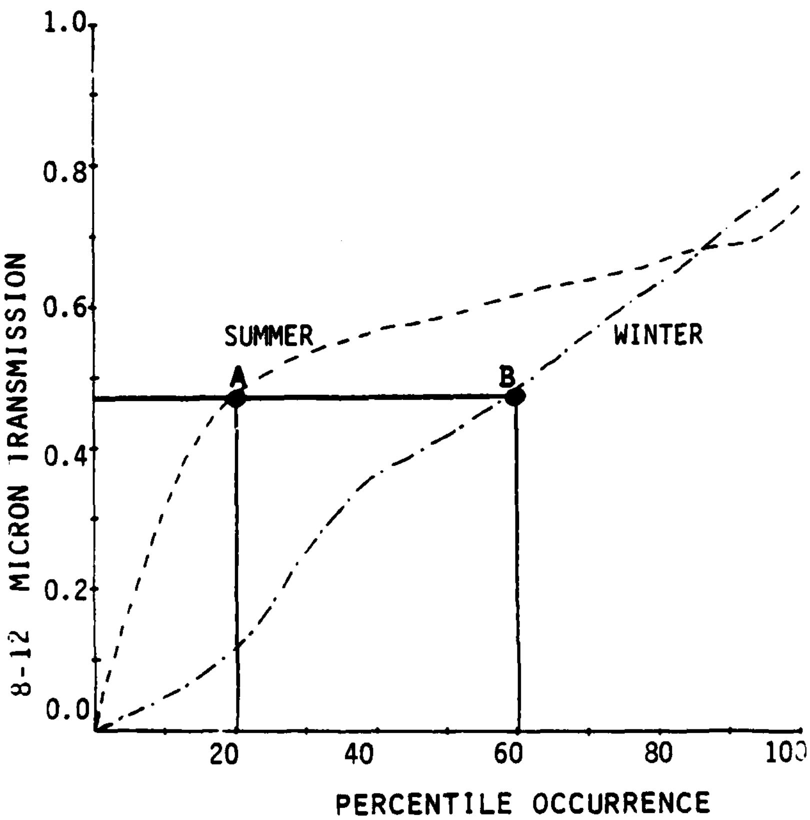


Figure 25. Hannover Winter Versus Summer Mid-Day Figure of Merit: Transmission.

M = TRANSMISSION x FLUX$^{1/2}$

T_{8-12} x FLUX $^{1/2}$

OCCURRENCE

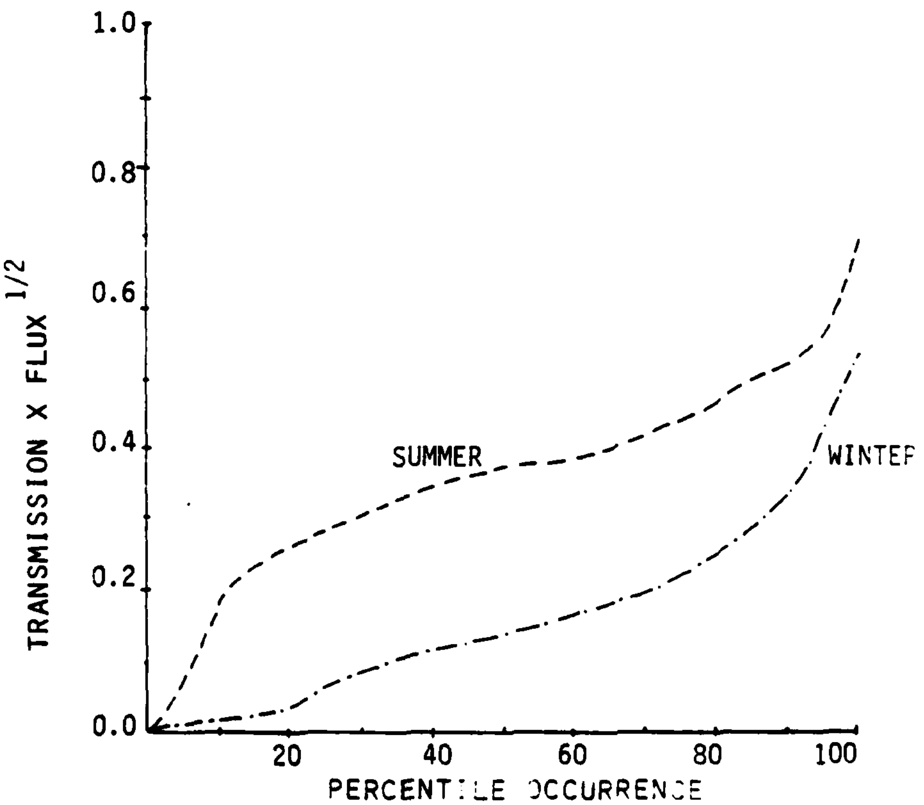


Figure 26. Hannover Winter Versus Summer Mid-Day Figure of Merit: Transmission Times Square Root of Flux.

M = TRANSMISSION x FLUX

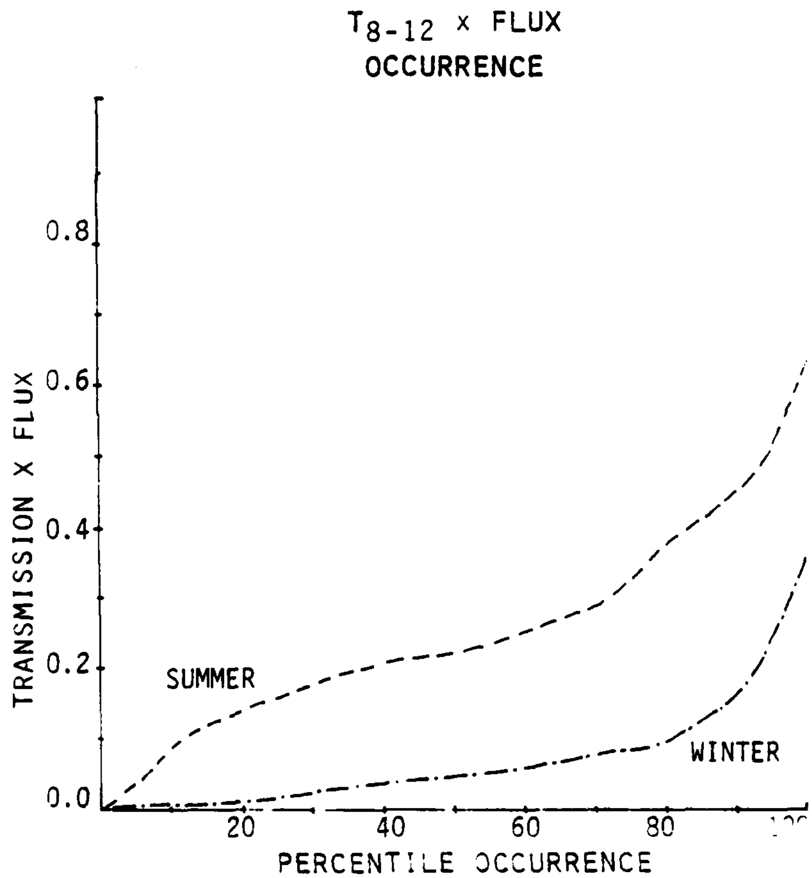


Figure 27. Hannover Winter Versus Summer Mid-Day Figure of Merit: Transmission Times Flux.

M = TRANSMISSION x FLUX$^{3/2}$

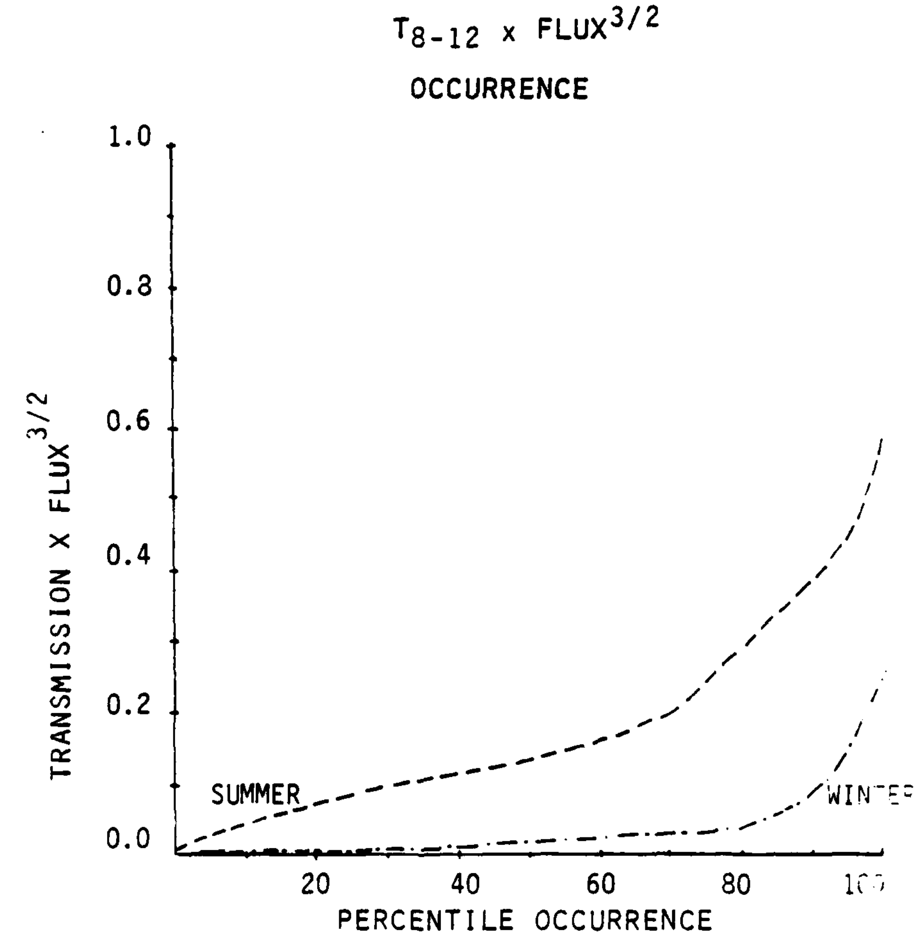


Figure 28. Hannover Winter Versus Summer Mid-Day Figure of Merit: Transmission Times Flux to Three Halves Power.

Figure 29 illustrates a similar comparison for a figure of merit, that included a wind speed exponential (15). As the figure shows, assuming this figure of merit is a reasonable measure of system performance, if the system works 80 percent of the time in the Summer, corresponding to a figure of merit value of .0367, it will work only about 12 percent of the time in the Winter, corresponding to the same figure of merit value.

4.2 PARAMETER CORRELATIONS

Of even more interest than single parameter occurrence statistics are cross correlation statistics. These statistics allow the determination of parameters which are most closely associated with system performance in the operational environment. This can be quite important. A parameter which would appear to have a significant effect on a system performance may not, because the parameter doesn't vary much in the operational environment, or because it is closely correlated to another parameter which tends to have a compensating effect. The opposite is also possible.

In addition to correlations based on direct physical effects, a factor having no direct effect may also correlate with performance simply because it closely correlates with other parameters which do strongly affect system performance. An example of such a parameter-- the relative humidity-- is, in fact, one of the interesting results of this study. Figure 30 is a good example of how this works. It correlates transmission in the 8-12 um band with relative humidity for Hannover Spring Mid-Day observations. To generate this plot, the following steps were necessary:

1. The sub-set of Hannover Spring Mid-Day observations were selected.

2. These observations were ranked, from those with the lowest relative humidity to those with the highest.

$M = \text{TRANSMISSION} \times \text{FLUX} \times e^{-V_w/5}$

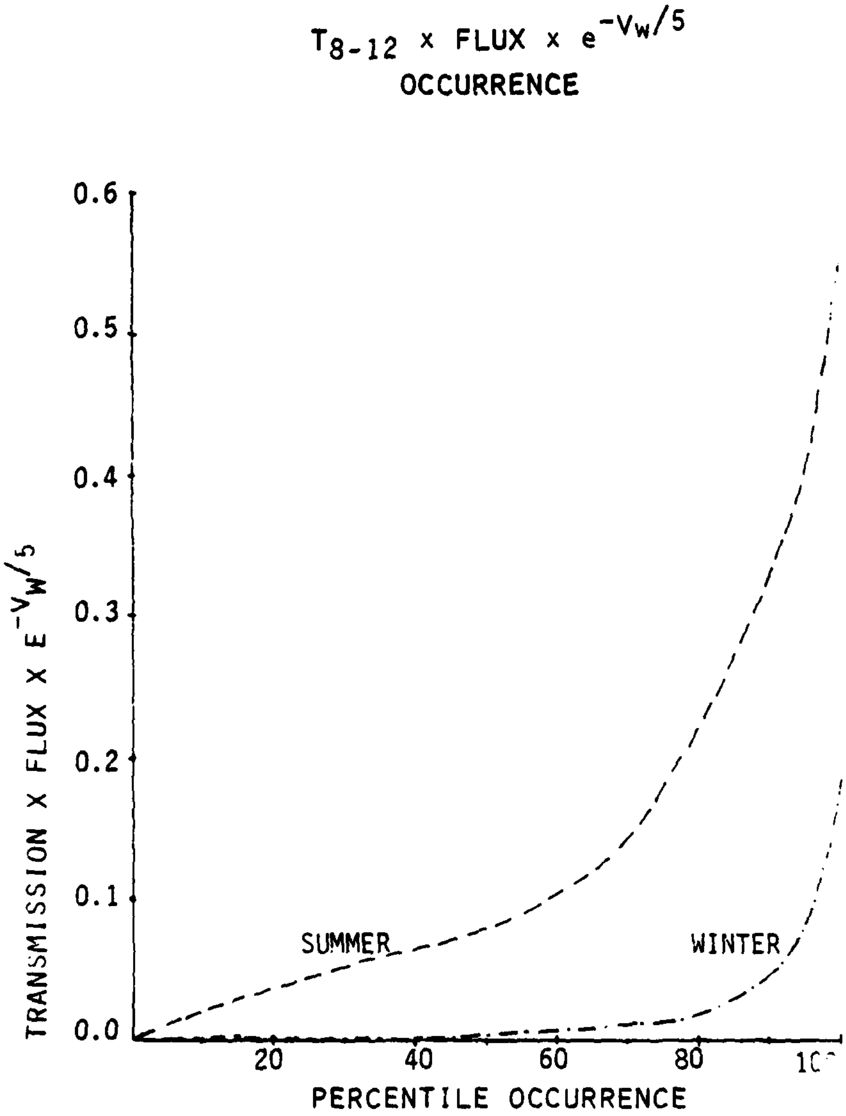


Figure 29. Hannover Winter Versus Summer Mid-Day Figure of Merit: Transmission Times Flux Times exp (-Wind Speed /5).

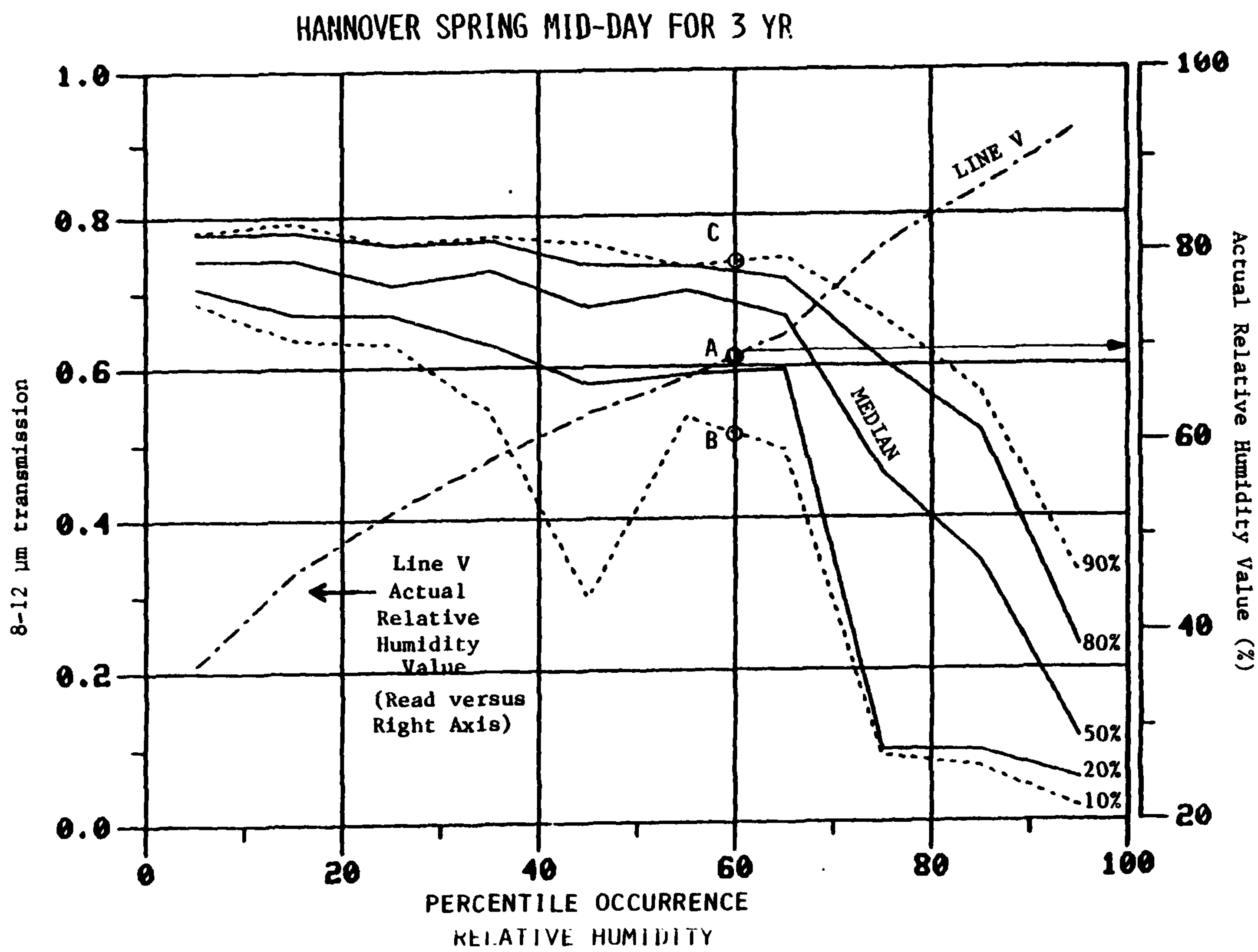


Figure 30. Correlation Plot: Hannover, Spring Mid-Day Relative Humidity Versus 8-12 um 4 km Transmission.

3. The resulting list was divided into ten "bins". The first bin had the 10 percent of the Hannover Spring Mid-Day observations with relative humidities lower than the other 90 percent; the second bin had 10 percent of the observations with the next higher relative humidity values, and so on.

4. Within each "bin", the observations were ranked with respect to a second parameter... in this case 8-12 um transmission. This allows the distribution of transmission correlated with the relative humidity to be evaluated.

5. In Figure 30 the line marked "Line V" is associated with the lower (percentile occurrence) and right hand (actual value) axes. The point A shows that the 60 percentile value (i.e., the value corresponding to a 60 percent cumulative frequency of occurrence) of relative humidity in this data set is 70 percent (actual relative humidity value).

6. Points B and C represent, respectively, the 10 percentile and 90 percentile values of the transmission (.5 and .75) associated with this relative humidity. The other lines are 20, 50, and 80 percentile values.

Note the key fact. The distribution of transmission associated with very low relative humidities has a preponderance of transmission values much higher than that associated with very high relative humidity values. This, of course, makes good sense... high relative humidities are strongly associated with fogs, precipitation, and aerosol growth. While relative humidity is a LOWTRAN 5 model input, single parameter sensitivity analysis indicates that this fact alone does not explain the degree of correlation. Sky cover, as another example, demonstrates significant correlation with horizontal transmission (Figure 33) and is not a model input at all. Thus, physical sensitivity as represented in the models does not fully explain the correlations. Since the correlation of relative humidity (or sky cover!), is in the data (hence, in the real world), correlations with other factors affecting transmission must be sought to provide the rest of the explanation.

By contrast, Figure 31 shows little correlation between absolute humidity and transmission. Of course, the 8-12 um band is strongly absorbed by atmospheric water vapor, but this effect is relatively minor compared with the enormous effect contributed by aerosols in this environment (Hannover Spring Mid-Day). It should be noted that in this location and season, absolute humidity rarely gets higher than 10 g m^{-3}, which is not enough to make absorption comparable to aerosol-induced extinction in most cases. Thus, little correlation between the occurrence of absolute humidity and 8-12 um transmission would be expected, even though there is a strong physical relationship involved.

For comparison, Figures 32, 33, 34, and 35 show four other cross correlations with 8-12 um transmission: Visibility, total sky cover, inferred rain rate, and calculated solar flux. In each case, high transmission is at least somewhat correlated with "good weather" values of the associated parameter--an intuitively satisfying result.

Of great interest is the correlation between relative humidity and the figure of merit values, within the value range actually occurring in the Hannover environment. Relative humidity proved to be strongly correlated with all figures of metit we investigated under virtually all circumstances. This was surprising when compared with, for example, visibility. Within the models used, visibility has an important direct physical effect on transmission at all wavelengths, because the aerosol number density is scaled to it. Relative humidity has less direct effects, but is associated with high absolute humidity (hence IR absorption) in warm weather, and large aerosols for high relative humidity values.

We suggest that the strong statistical correlation of all these figures of merit with the occurrence of high relative humidity may simply reflect the general correlation between high relative humidity and bad weather, and between low relative humidity and good weather. In addition to the relationships mentioned in the last paragraph, high relative

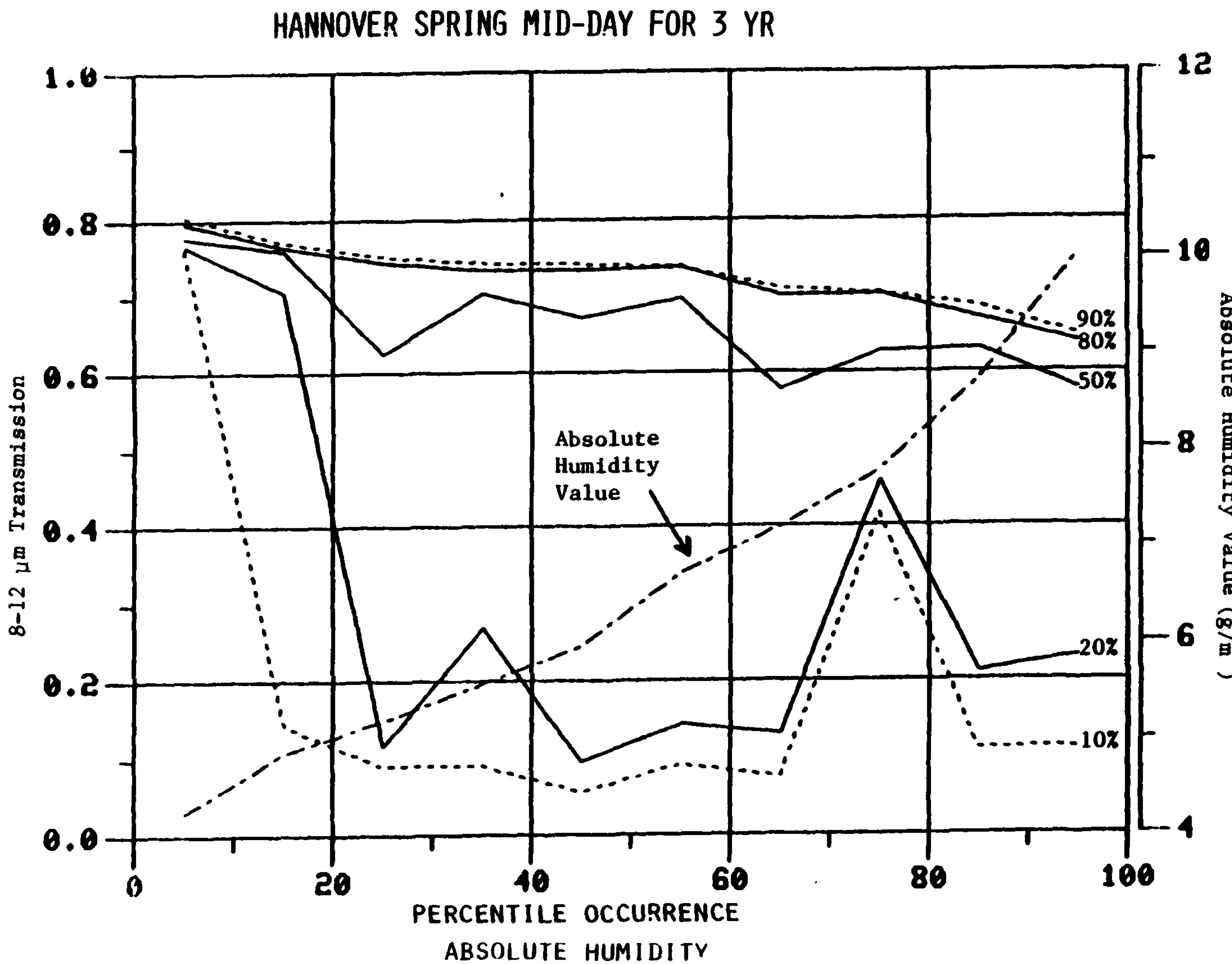


Figure 31. Correlation Plot: Hannover, Spring Mid-Day Absolute Humidity Versus 8-12 um 4 km Transmission.

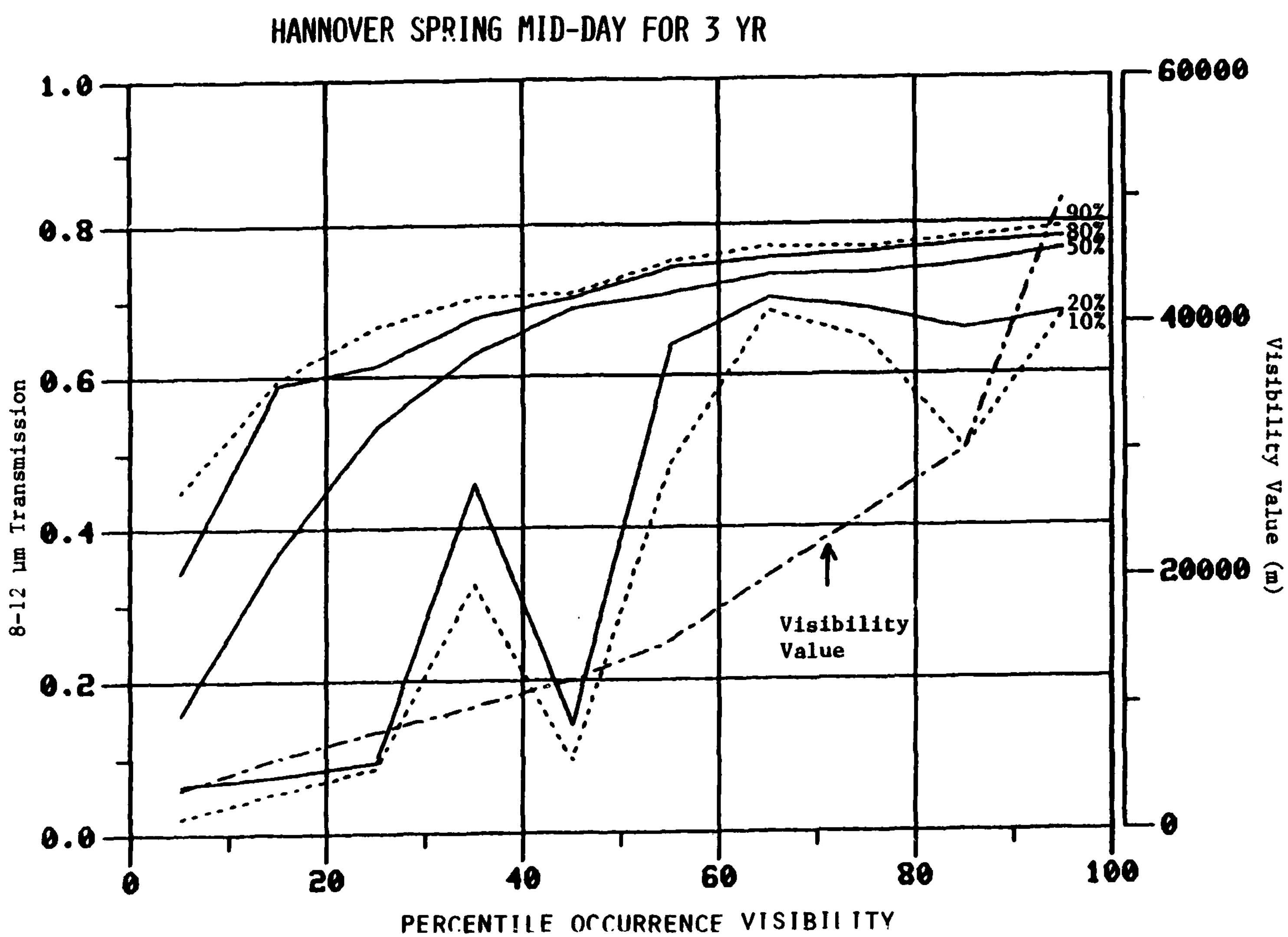


Figure 32. Correlation Plot: Hannover, Spring Mid-Day Visibility Versus 8-12 um 4 km Transmission.

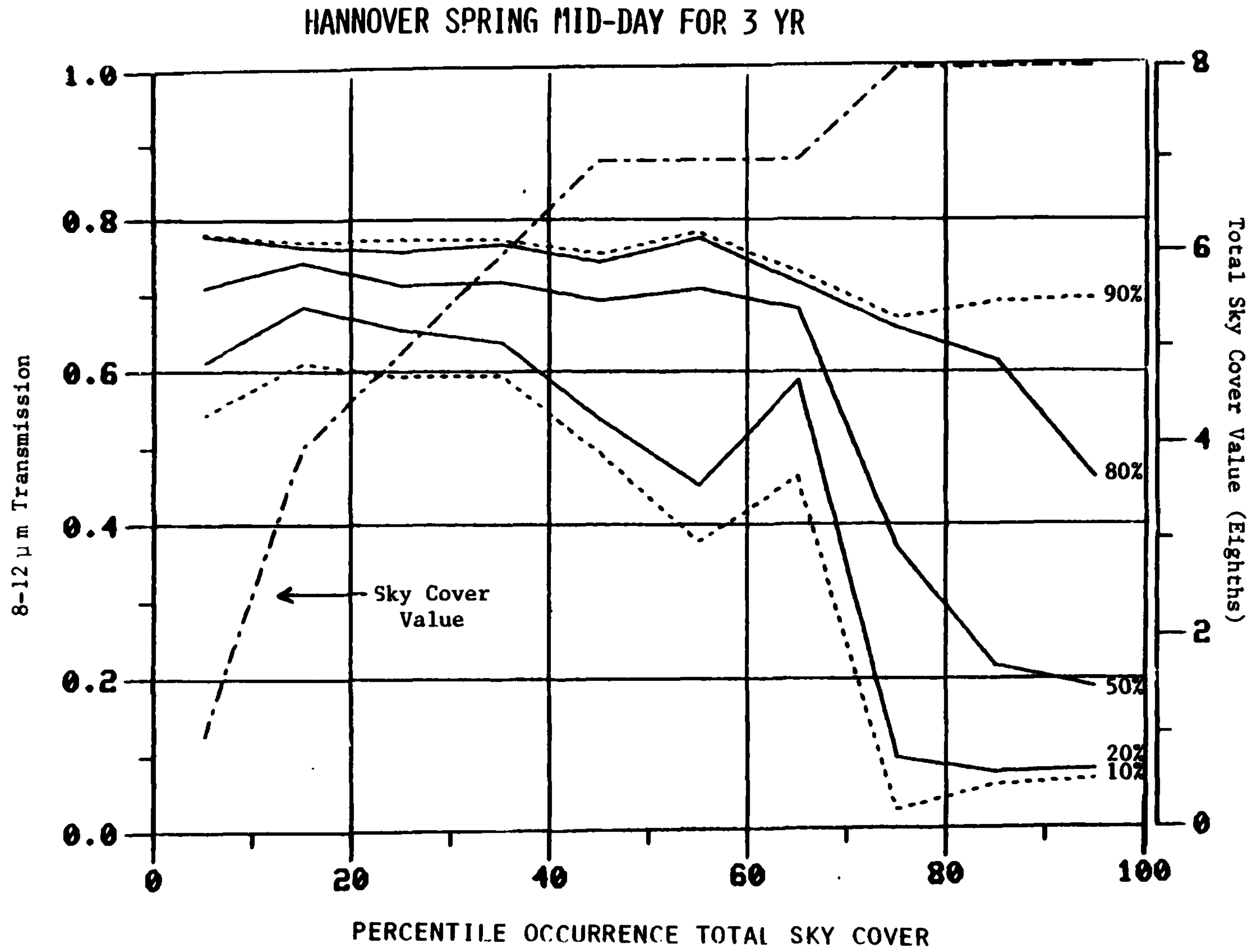


Figure 33. Correlation Plot: Hannover, Spring Mid-Day Total Sky Cover Versus 8-12 um 4 km Transmission.

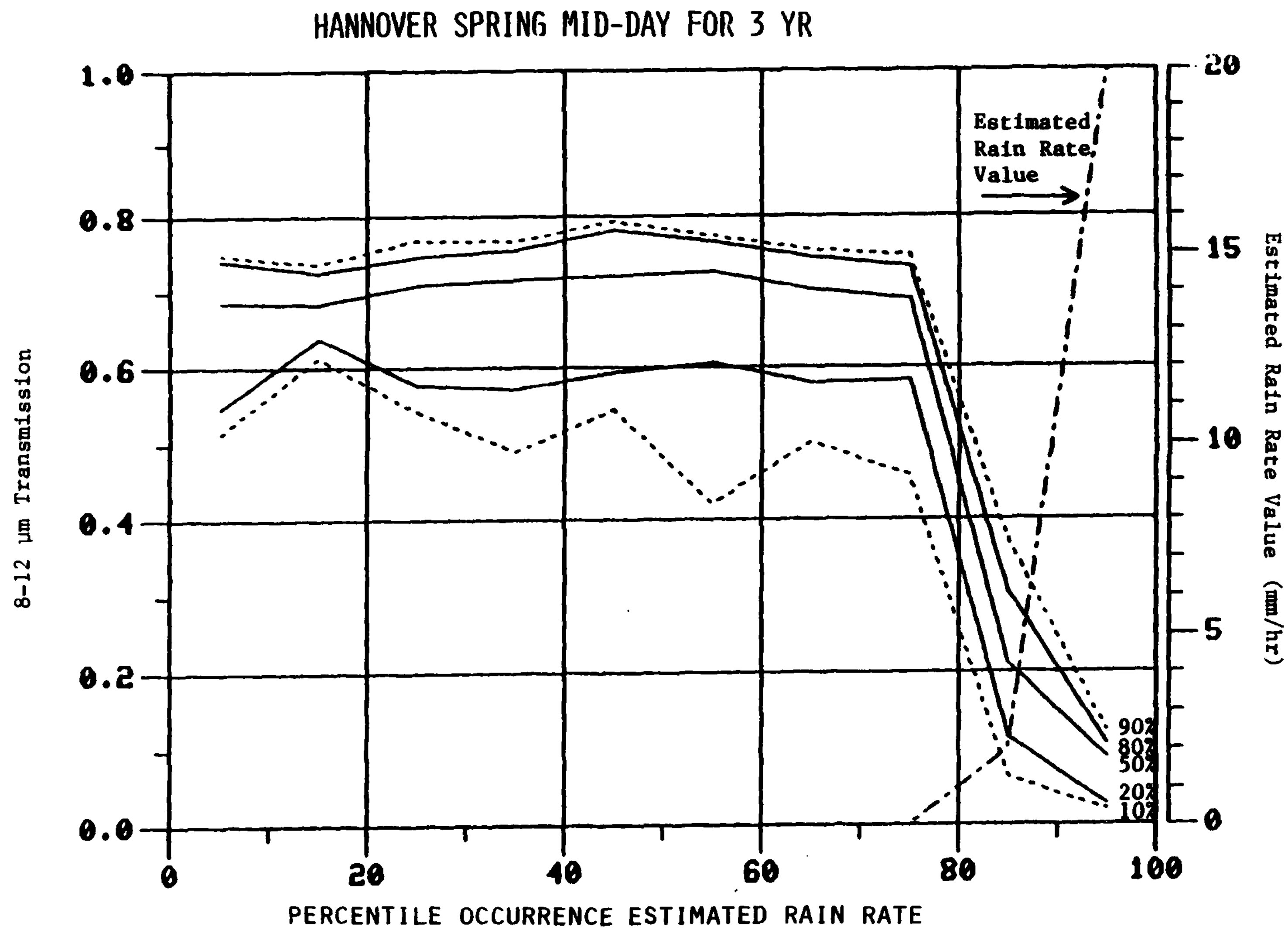


Figure 34. Correlation Plot: Hannover, Spring Mid-Day Estimated Rain Rate Versus 8-12 um 4 km Transmission.

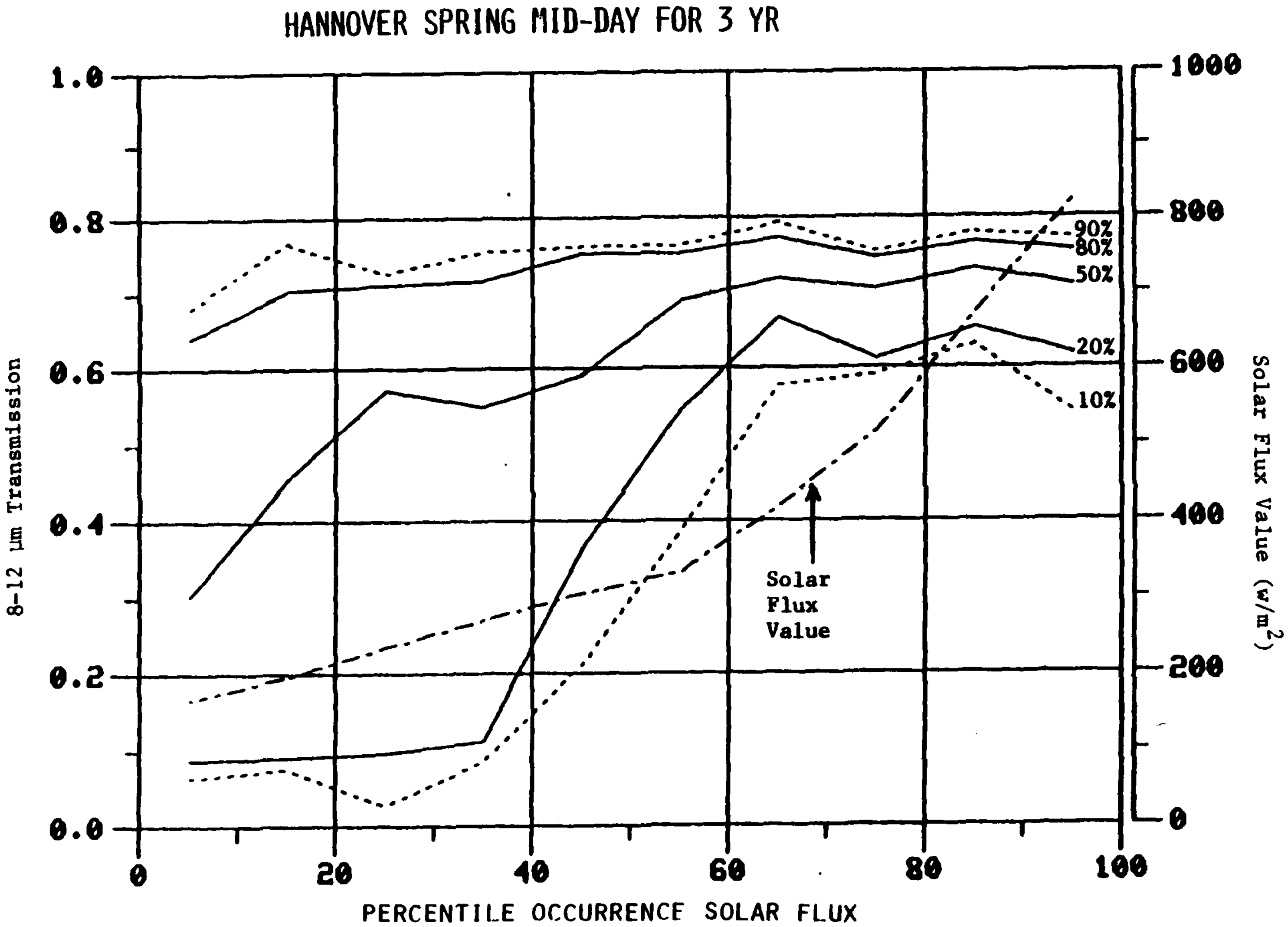


Figure 35. Correlation Plot: Hannover, Spring Mid-Day Calculated Solar Flux Versus 8-12 um 4 km Transmission.

humidity is also correlated with precipitation (a high extinction phenomenon), fog (a low visibility, low transmission phenomenon) and generally inclement weather: clouds (reducing solar flux) high winds (affecting the wind-related figure of merit), etc. Thus, relative humidity's correlation may simply reflect a correlation with many separate factors, which collectively improve or degrade sensor performance.

Figures 36, and 37 show the correlation of relative humidity and visibility, respectively, to a figure of merit which includes solar flux: Transmission times flux. Figures 38 and 39 show the correlation of relative humidity and visibility, respectively, to the wind-related figure of merit: Transmission times flux times $\exp(-V_w/5)$ (wind speed in m s^{-1}). Note that, in these figures, T_{8-12} is used as a short form to mean 8-12 um transmission over a 4 km horizontal path. The close correlation of relative humidity is unmistakable. This is borne out by calculation of linear coefficients of determination (r^2). In brief, $r^2=0$ implies no correlation, while $r^2=1$ would imply perfect linear correlation. Though obviously not a strictly linear function, the linear fits and their coefficients of determination are quite good, as shown in Table 4, which includes formulas for calculating r^2 and other related statistical quantities.

Note also that absolute humidity correlates much more closely with IR transmission in Summer. This is expected because, in Summer, the air is frequently warm enough to allow absolute humidity to reach levels at which water vapor absorption it becomes a major factor associated with overall IR extinction. On the other hand, relative humidity and visibility demonstrate strong correlations at all times of year.

It must be remembered that these results, and others like them, are based on the patterns inherent in local weather. The specific results for a specific system and a given set of data will only be valid for locations, seasons, and/or times of day having weather behavior similar to that used in the analysis. The Mid-East, for example, could show significantly different parameter correlations.

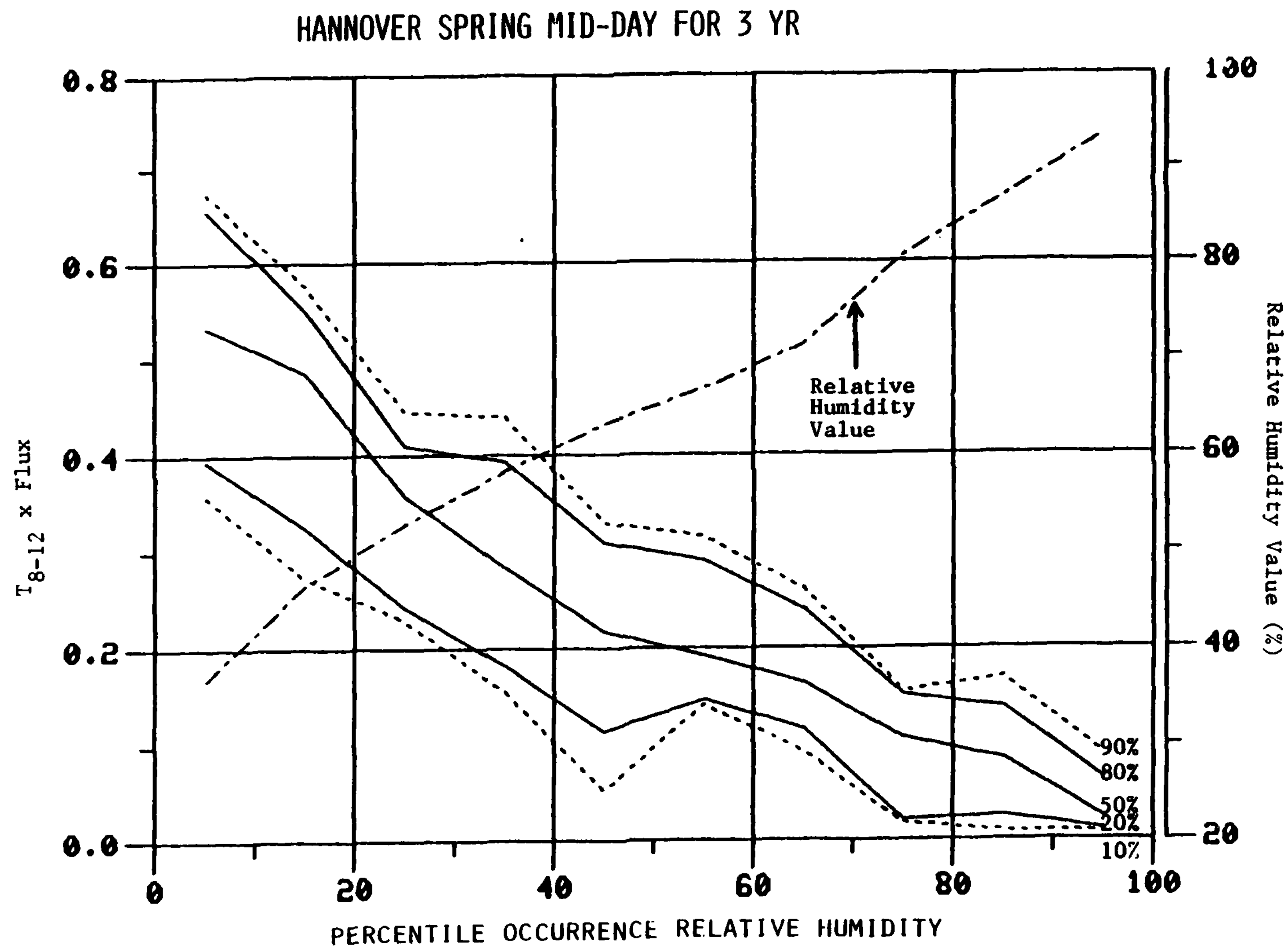


Figure 36. Correlation Plot: Hannover, Spring Mid-Day Relative Humidity Versus [T_{8-12} Times Flux].

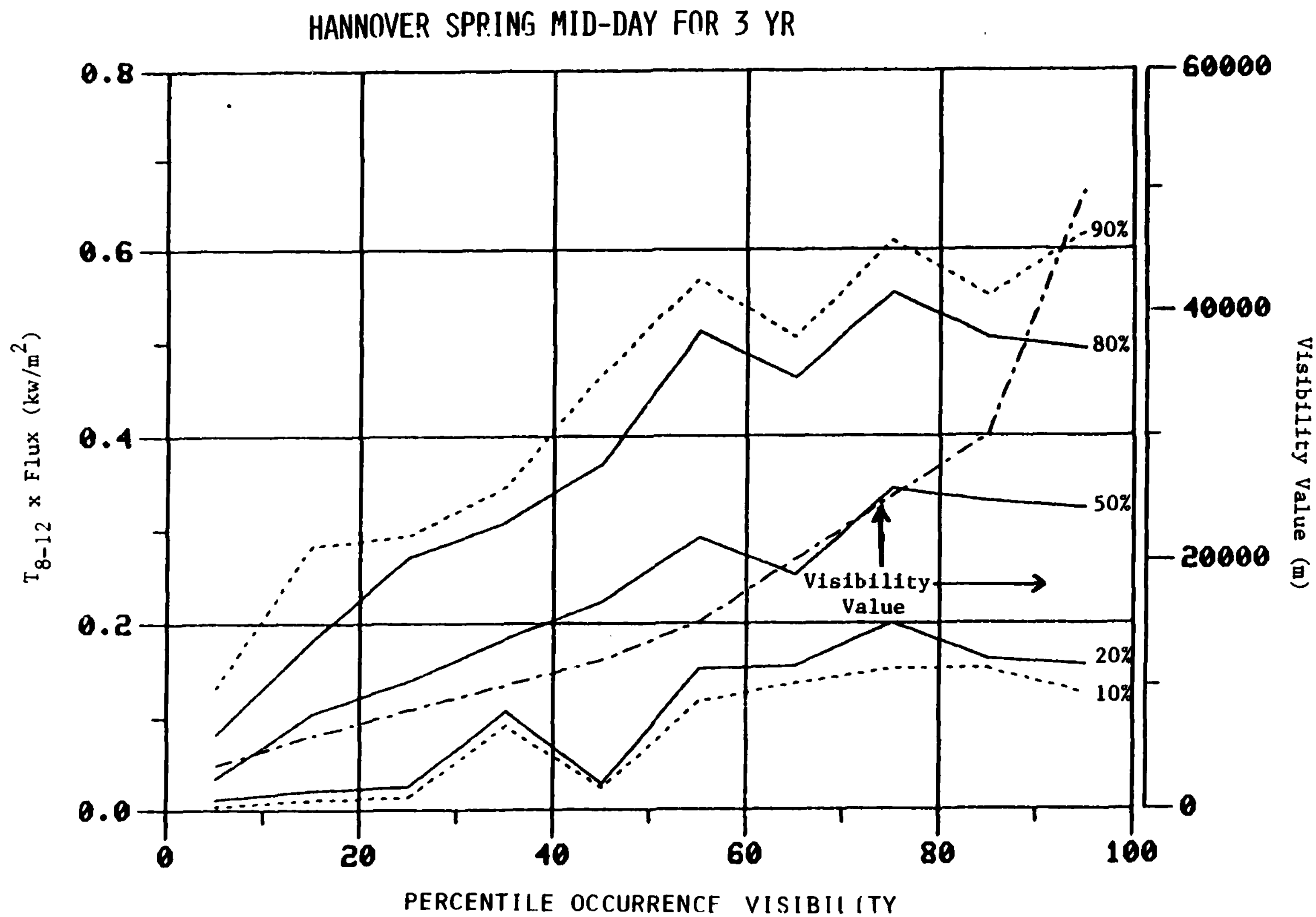


Figure 37. Correlation Plot: Hannover, Spring Mid-Day Visibility Versus [T_{8-12} Times Flux].

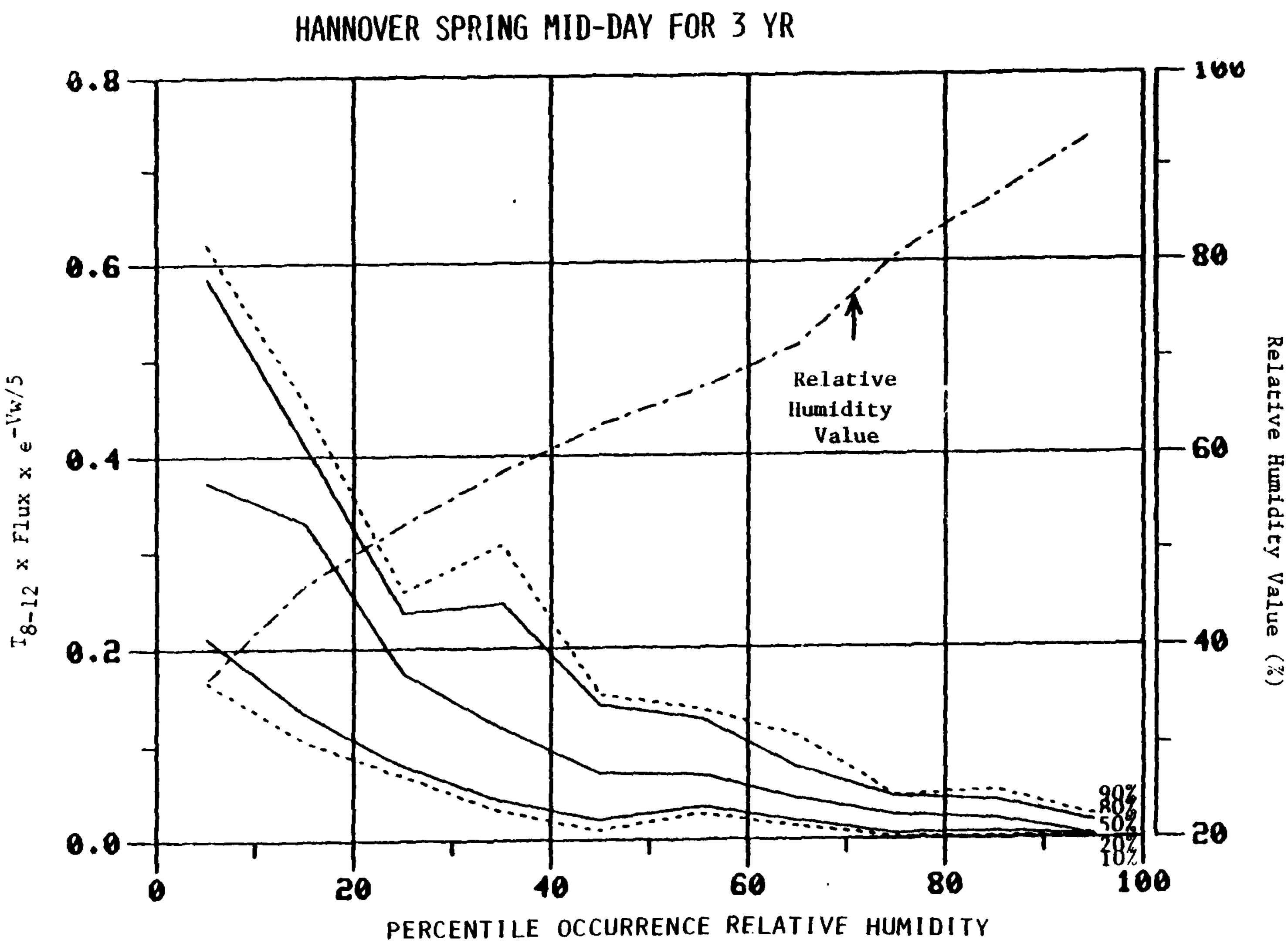


Figure 38. Correlation Plot: Hannover, Spring Mid-Day Relative Humidity Versus [T_{8-12} Times Flux Times $e^{-V_w/5}$].

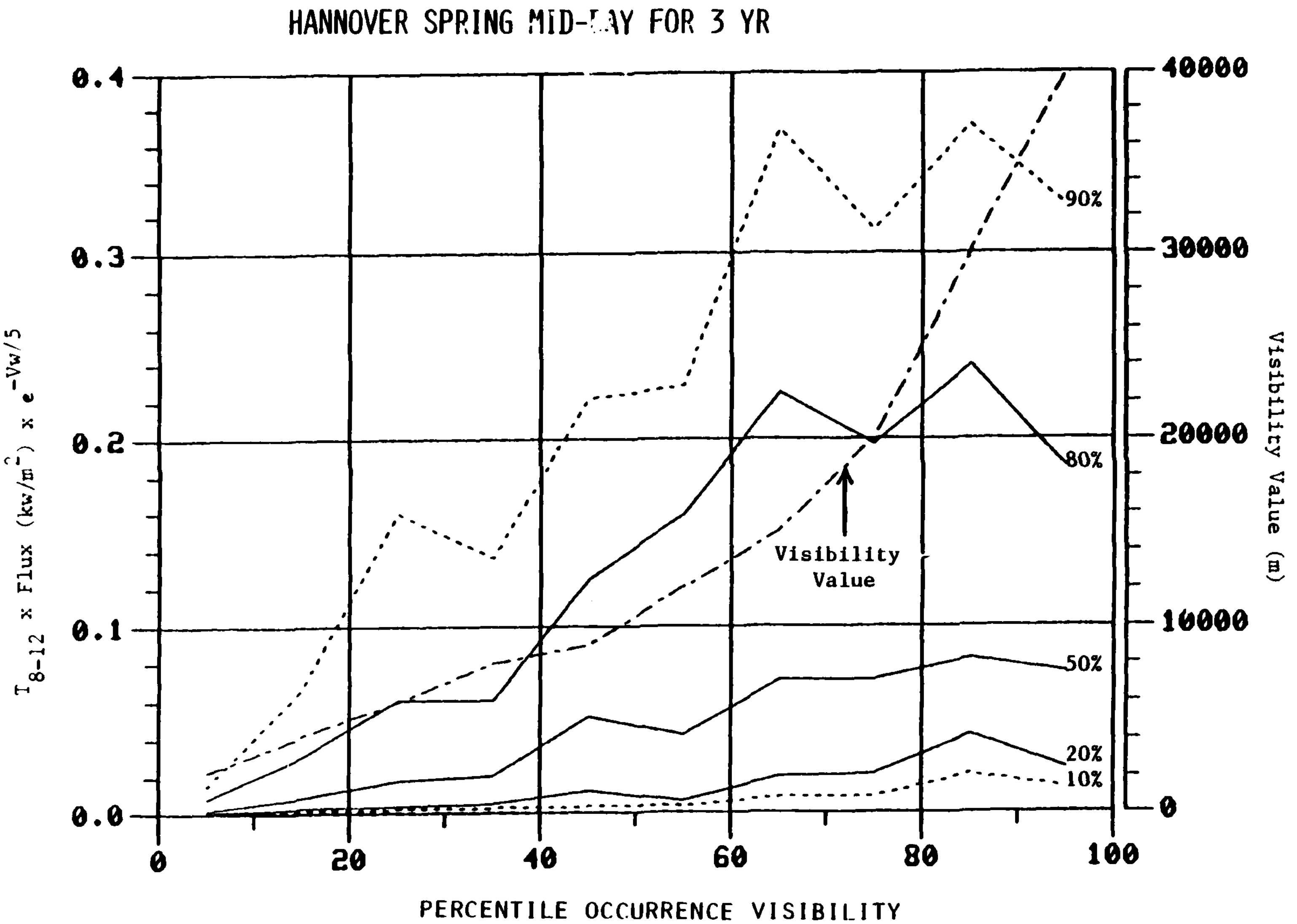


Figure 39. Correlation Plot: Hannover, Spring Mid-Day Visibility Versus [T_{8-12} Times Flux Times $e^{-V_w/5}$] Wind Speed in m s^{-1}.

Table 4. Hannover, Spring Mid-Day Coefficient of Determination

FIGURE OF MERIT Versus	Season	Relative Humidity (Percent)	Absolute Humidity (g/m^3)	Visibility (km)
Transmission	Winter	.777	.019	.627
	Spring	.747	.251	.561
	Summer	.727	.552	.602
Transmission Times Solar Flux	Winter	.712	.148	.427
	Spring	.839	.031	.481
	Summer	.771	.144	.281
Transmission Times Solar Flux Times $Exp(V_W/5)$	Winter	.560	.153	.316
	Spring	.741	.064	.387
	Summer	.636	.017	.137

Coefficient of Determination =

$$\text{Correlation Coefficient} = r^2 = \frac{cov(x,y)}{s_x s_y}$$

$$cov(x,y) = \text{covariance of } x \text{ and } y = \frac{\sum_{i=1}^{n} x_i y_i}{n} - \overline{xy}$$

$$s_x^2 = \text{variance of } x = \frac{\sum_{i=1}^{n} x_i}{n} - \bar{x}^2 \qquad s_x = \text{standard deviation in } x$$

$$s_y^2 = \text{variance of } y = \frac{\sum_{i=1}^{n} y_i}{n} - \bar{y}^2 \qquad s_y = \text{standard deviation in } y$$

Figure 40 shows a different kind of comparison that could be of considerable interest to planners. Figure 40, a Giessen Spring Dawn scenario, shows the correlated distribution of cloud base height with low cloud cover. In this environment, median (50 percentile) cloud cover is about 6/8 (read dot-dash line to right-hand scale). In these median cloud cover conditions (actually, conditions ranging from about 5/8 (45 percentile) to 7/8 (55 percentile), 80 percent of the time, the base of the clouds is between 400 meters (10 percentile) to 1000 meters (90 percentile), with a median (50 percentile) value of 600 meters above the surface. One can also see that 60 percent of the time, the low cloud cover will be at least 4/8, and that, in these cases, 90 percent of the time, the cloud base will be at 1,000 meters or less. Combining occurrence probabilities, 54 percent of the time, the cloud condition will be $\geq$4/8 cover at $\leq$1,000 meters.

Figure 41 shows Winter Dawn conditions. Seventy percent of the time, the low cloud cover is at least 7/8; of those occasions, 80 percent of the time, the cloud base height is 600 meters or less.

This information, for example, would be directly applicable to scenarios involving "smart" artillery shells using semi-active IR homing to find ground-illuminated targets. A low heavy cloud base could force the use of very flat artillery trajectories to provide adequate lock-on and guidance time... or rule out use of smart rounds all together.

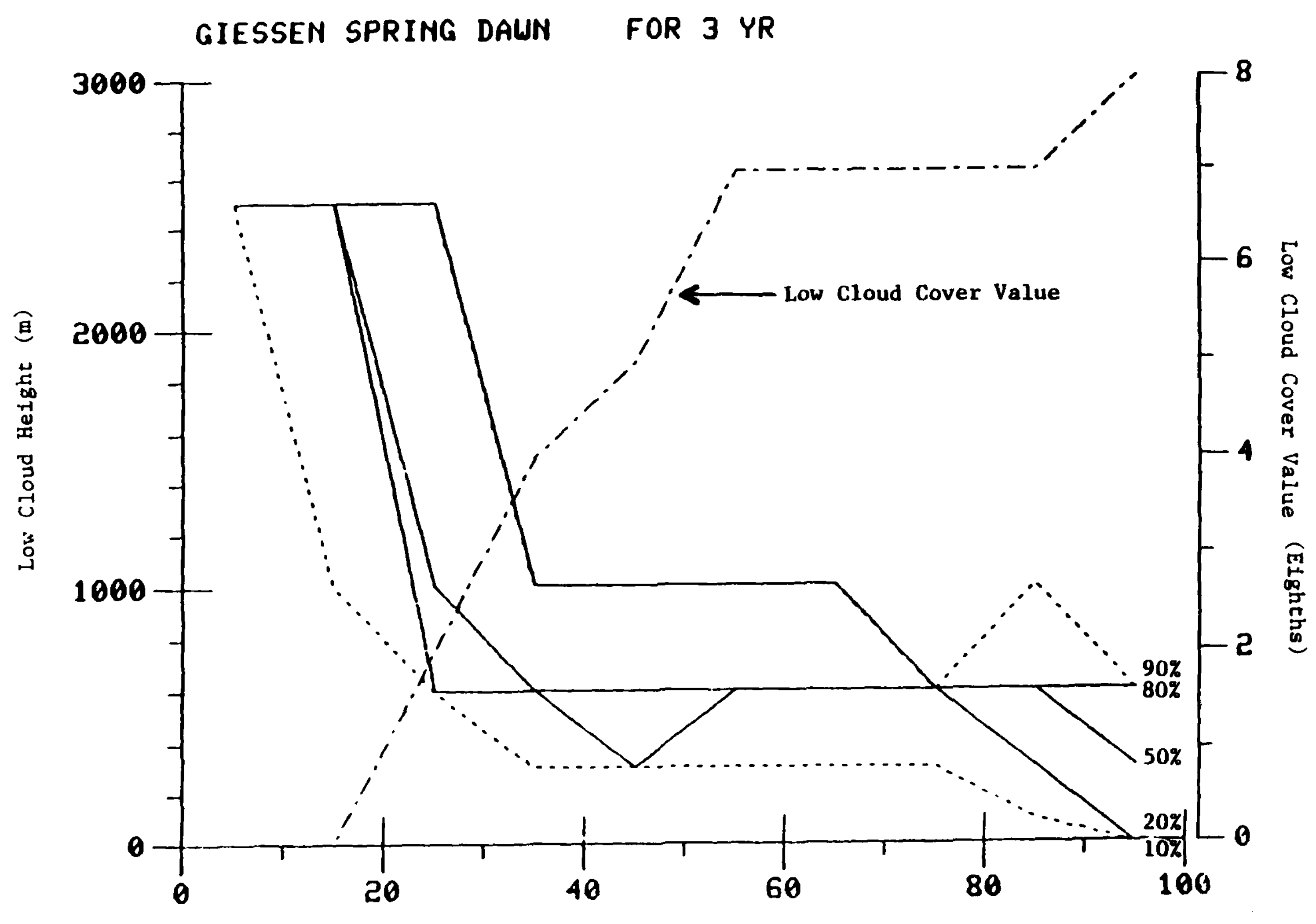


Figure 40. Correlation Plot: Giessen, Spring Dawn Low Cloud Cover Versus Low Cloud Height.

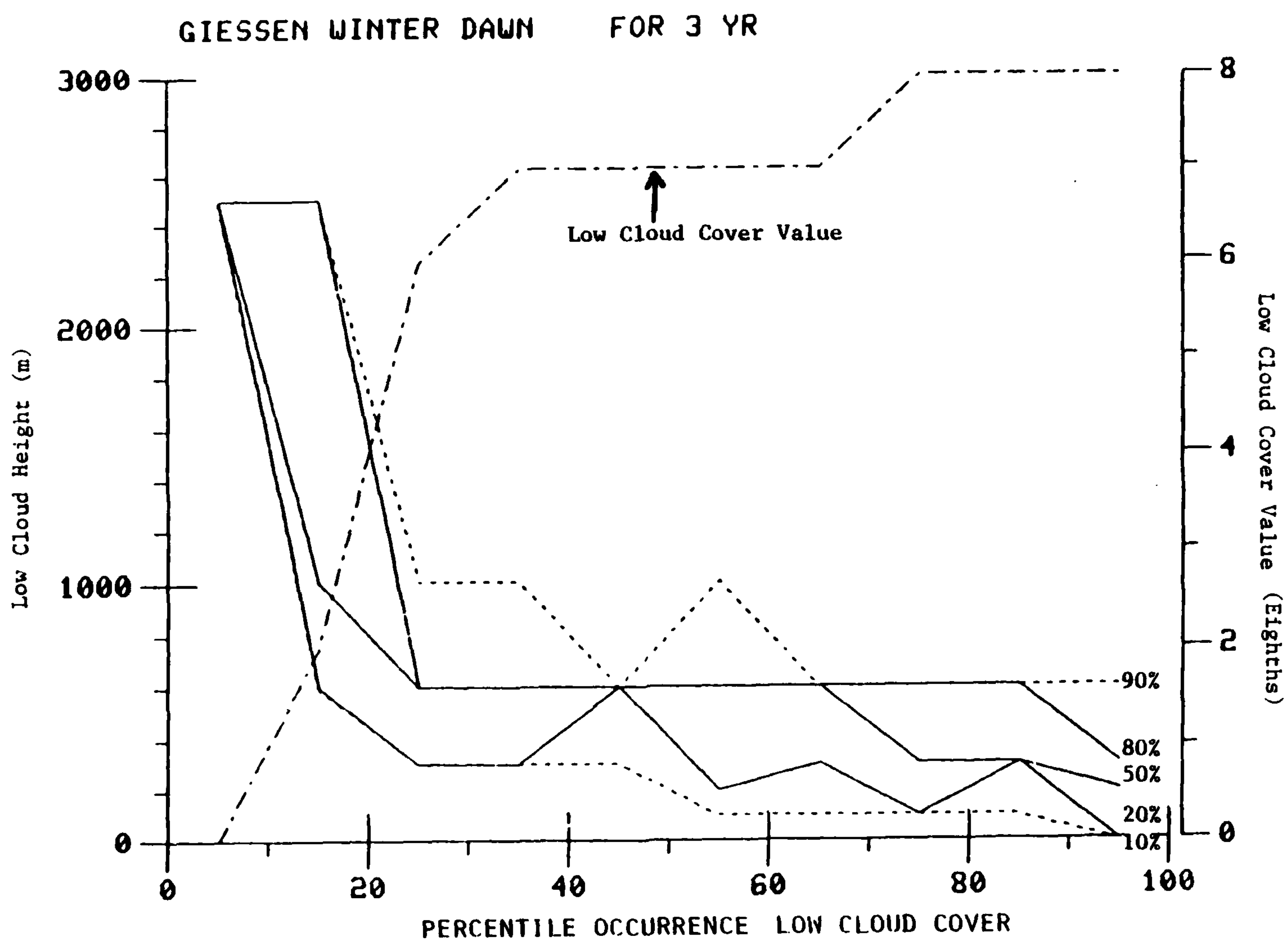


Figure 41. Correlation Plot: Giessen, Winter Dawn Low Cloud Cover Versus Low Cloud Height.

SECTION 5

CONCLUSIONS

The utility of this data base for statistical analysis has scarcely been touched. Only a few correlations have been investigated, and only a small number of stations analyzed. However, even at this stage, some interesting preliminary results seem worthy of further investigation.

First, and most important, data are available for applying meteorology to system performance analysis. In view of this fact, and the increasing interest at the Office of the Under Secretary of Defense for Research and Engineering (OUSDR&E) level, these analysis techniques will become increasingly important.

Second, many aspects of weather-related phenomena can be addressed via the use of inferential models, such as LOWTRAN 5. As these models are perfected, increasing sophistication in analyses linking sensor performance to weather occurrence will be possible.

Third, while a complete system performance model for IR sensors has not yet been developed, several figures of merit are available. These include the transmission, the solar flux (suggesting inherent target contrast), and various combinations of these two parameters. More sophisticated figures of merit, such as that involving wind speed briefly examined here, and, eventually, the actual calculated or measured performance of the systems, will be available in these analyses.

Finally, such analyses can yield interesting operational conclusions. For example, the importance of relative humidity as an indicator of sensor performance in some environments suggests that a very good estimate of the performance of a sensor in enemy territory may be obtainable from little more than a good relative humidity measurement or forecast. This could be of considerable importance in supporting the use of precision guided munitions. As another example, the correlations between cloud conditions, visibility and other weather parameters could have considerable impact on the projected utilization of other smart munitions, such as Copperhead, where factors such as designation range and Cloud-Free-Line-Of-Sight (CFLOS) are important considerations.

SECTION 6

NEW HORIZONS

This study leaves many questions unanswered and many potentially important issues unaddressed. The following are a few major areas for further work and study.

- Full performance models for EO systems of interest should be developed to fully utilize the power of this analysis technique. So far, this technique has only been fully realized for surface based HEL weapon analysis (2). Interesting systems for future analysis include:

  - IR Warning Receivers
  - Laser IR Countermeasures
  - Optical Countermeasures
  - Pyrophoric and Pyrotechnic Flares
  - Obscurant Countermeasures
  - FLIR Sensors
  - IR Search/Track Systems
  - Imaging IR, TV, and Laser Designated Precision Guided Munitions
  - Millimeter/sub-millimeter wavelength systems

- Better correlation models must be developed. Further work is necessary in the area of atmospheric transmission, particularly correlating current observables to aerosol extinction. Also very important are target/background signature models, such as those now being developed from data taken at the AFATL.

- The data base and associated analysis technique should be extended to 3 dimensions. This analysis in this study was based entirely upon surface data. The Avionics Laboratory (AFWAL/AAWA) is currently obtaining from USAFETAC an integrated data base including surface, boundary layer, upper air, and cloud (3 Dimensional Nephanalysis) data. This integrated data base, covering Europe, the Near East, the Soviet Union, the Mediterranean, and North Africa (see Figure 42) at 25 nautical miles, 3 hour, 16 altitude level resolution, will allow virtually any kind of weather related effectiveness analysis to be accomplished, including surface conditions, vertical atmospheric profiles, and detailed cloud conditions.

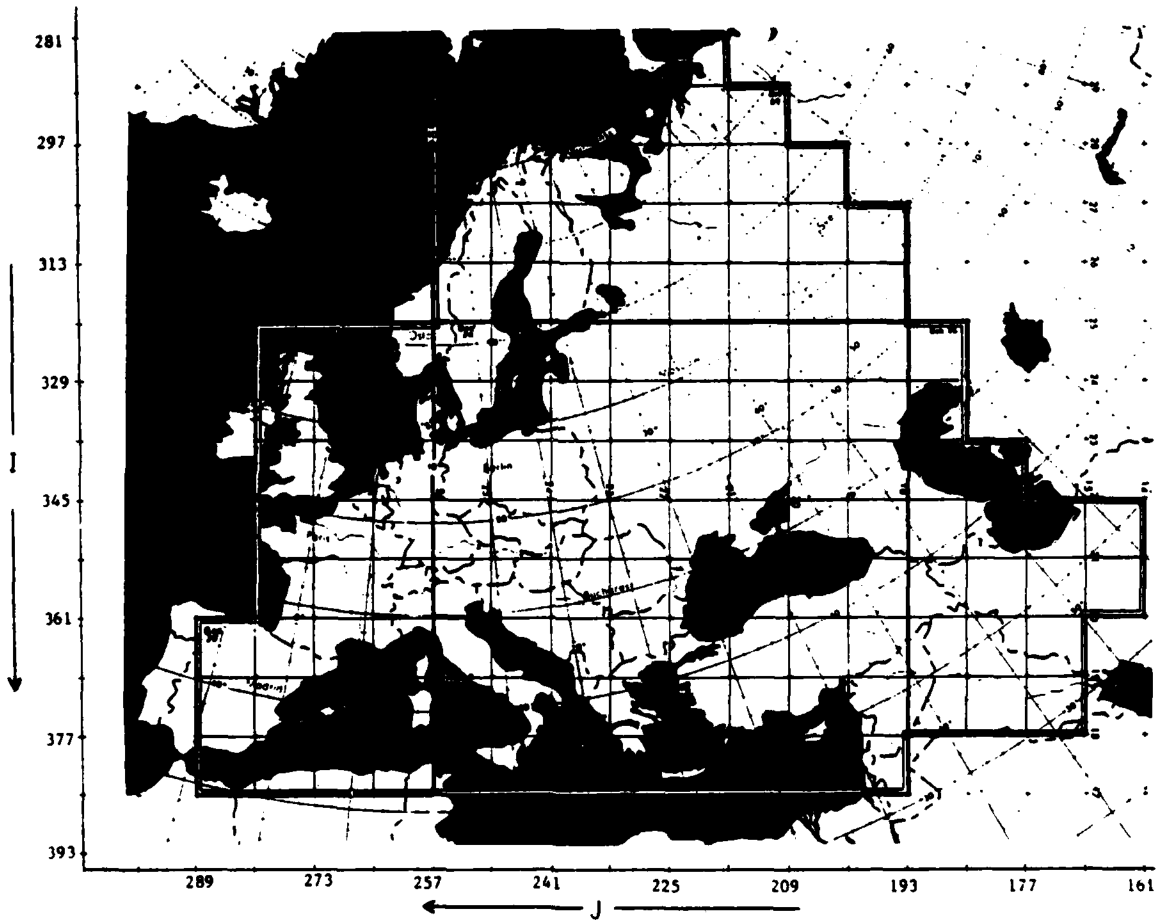


Figure 42. Integrated Data Base Geographic Coverage.

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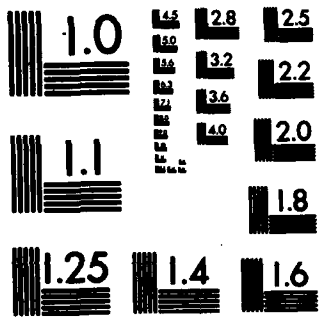

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